USER MANUAL

DMC-18x2

Manual Rev. 1.0i

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Using This Manual

This user manual provides information for proper operation of the DMC-18x2 controller. A separate supplemental manual, the Command Reference, contains a description of the commands available for use with this controller.

Your DMC-18x2 motion controller has been designed to work with both servo and stepper type motors. Installation and system setup will vary depending upon whether the controller will be used with stepper motors or servo motors. To make finding the appropriate instructions faster and easier, icons will be next to any information that applies exclusively to one type of system. Otherwise, assume that the instructions apply to all types of systems. The icon legend is shown below.

Attention: Pertains to servo motor use.

Attention: Pertains to stepper motor use.

Please note that many examples are written for the DMC-1842 four-axes controller. Users of the DMC-1832 3-axis controller, DMC-1822 2-axes controller or DMC-1812 1-axis controller should note that the DMC-1832 uses the axes denoted as XYZ, the DMC-1822 uses the axes denoted as XY, and the DMC-1812 uses the X-axis only.

WARNING: Machinery in motion can be dangerous! It is the responsibility of the user to design effective error handling and safety protection as part of the machine. Galil shall not be liable or responsible for any incidental or consequential damages.

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Chapter 1 Overview

Introduction

The DMC-18x2 series motion control cards install directly into the PCI bus. This controller series offers many enhanced features including high speed communications, non-volatile program memory, faster encoder speeds, and improved cabling for EMI reduction.

The DMC-18x2 provides a high speed FIFO for sending and receiving commands. This PCI bus motion controller allows for high speed servo control up to 12 million encoder counts/sec and step motor control up to 3 million steps per second. Sample rates as low as 62.5µsec per axis are available.

A 2 meg Flash EEPROM provides non-volatile memory for storing application programs, parameters, arrays and firmware. New firmware revisions are easily upgraded in the field without removing the controller from the PC.

The DMC-18x2 is available with up to four axes on a single PCI card. The DMC-1812, 1822, 1832, and 1842, one thru four axes controllers, are on a single 4.23" x 9" card.

Designed to solve complex motion problems, the DMC-18x2 can be used for applications involving jogging, point-to-point positioning, vector positioning, electronic gearing, multiple move sequences, and contouring. The controller eliminates jerk with programmable acceleration, deceleration, and profile smoothing. For seamless following of complex contours, the DMC-18x2 provides continuous vector feed of an infinite number of linear and arc segments. The controller also features electronic gearing with multiple master axes as well as gantry mode operation.

For synchronization with outside events, the DMC-18x2 provides uncommitted I/O, including 8 digital inputs, and 8 digital outputs. Committed digital inputs are provided for forward and reverse limits, abort, home, and definable input interrupts. Commands can be sent in either Binary or ASCII. Additional software is available to autotune, view trajectories on a PC screen, translate CAD.DXF files into motion, and create powerful, application-specific operator interfaces with Visual Basic, Labview and others. Drivers for DOS, Windows 3.1, 95, 98, 98SE, ME, NT4.0, 2000, XP, QNX, and Linux are available.

Overview of Motor Types

The DMC-18x2 can provide the following types of motor control:

1. Standard servo motors with +/- 10 volt or PWM command signals
2. Brushless servo motors with sinusoidal commutation
3. Step motors with step and direction signals
4. Other actuators such as hydraulics - For more information, contact Galil.

The user can configure each axis for any combination of motor types, providing maximum flexibility.

Standard Servo Motors with +/- 10 Volt Command Signal

The DMC-18x2 achieves superior precision through use of a 16-bit motor command output DAC and a sophisticated PID filter that features velocity and acceleration feedforward, an extra pole filter and integration limits.

The controller is configured by the factory for standard servo motor operation. In this configuration, the controller provides an analog signal (+/- 10Volt) to connect to a servo amplifier. This connection is described in Chapter 2.

Brushless Servo Motor with Sinusoidal Commutation

The DMC-18x2 can provide sinusoidal commutation for brushless motors (BLM). In this configuration, the controller generates two sinusoidal signals for connection with amplifiers specifically designed for this purpose.

Note: The task of generating sinusoidal commutation may be accomplished in the brushless motor amplifier. If the amplifier generates the sinusoidal commutation signals, only a single command signal is required and the controller should be configured for a standard servo motor (described above).

Sinusoidal commutation in the controller can be used with linear and rotary BLMs. However, the motor velocity should be limited such that a magnetic cycle lasts at least 6 milliseconds*. For faster motors, please contact the factory.

The controller provides a one-time, automatic set-up procedure. The parameters determined by this procedure can then be saved in non-volatile memory to be used whenever the system is powered on.

The DMC-18x2 can control BLMs equipped with Hall sensors as well as without Hall sensors. If hall sensors are available, once the controller has been setup, the controller will estimate the commutation phase upon reset. This allows the motor to function immediately upon power up. The hall effect sensors also provide a method for setting the precise commutation phase. Chapter 2 describes the proper connection and procedure for using sinusoidal commutation of brushless motors.

* 6 Milliseconds per magnetic cycle assumes a servo update of 1 msec (default rate).

Stepper Motor with Step and Direction Signals

The DMC-18x2 can control stepper motors. In this mode, the controller provides two signals to connect to the stepper motor: Step and Direction. For stepper motor operation, the controller does not require an encoder and operates the stepper motor in an open loop. Chapter 2 describes the proper connection and procedure for using stepper motors.

DMC-18x2 Functional Elements

The DMC-18x2 circuitry can be divided into the following functional groups as shown in Figure 1.1 and discussed below.

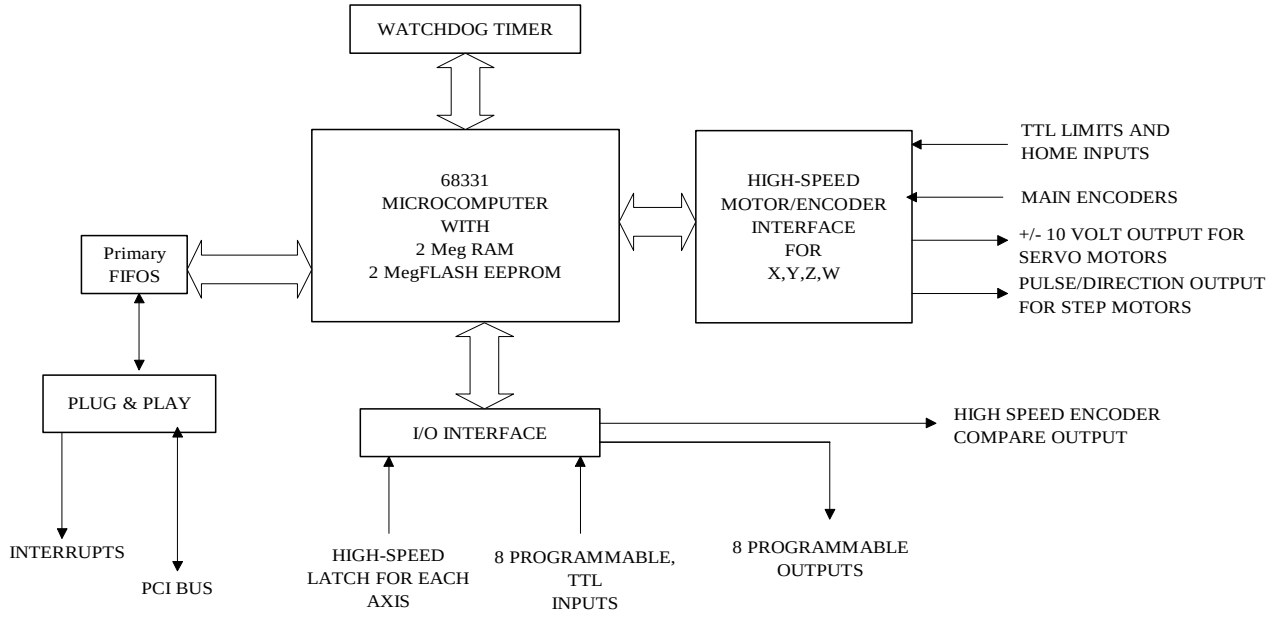

Figure 1.1 - DMC-18x2 Functional Elements

Microcomputer Section

The main processing unit of the DMC-18x2 is a specialized 32-bit Motorola 68331 Series Microcomputer with 2 Meg RAM and 2 Meg Flash EEPROM. The RAM provides memory for variables, array elements and application programs. The flash EEPROM provides non-volatile storage of variables, programs, and arrays. It also contains the DMC-18x2 firmware.

Motor Interface

Galil's GL-1800 custom, sub-micron gate array performs quadrature decoding of each encoder at up to 12 MHz. For standard servo operation, the controller generates a +/-10 Volt analog signal (16 Bit DAC). For sinusoidal commutation operation, the controller uses 2 DACs to generate 2 +/-10Volt analog signals. For stepper motor operation, the controller generates a step and direction signal.

Communication

The communication interface with the host PC contains a bi-directional FIFO (AM4701) and includes PC interrupt handling circuitry.

General I/O

The DMC-18x2 provides interface circuitry for 8 TTL inputs and 8 TTL outputs. The general inputs can also be used for triggering a high speed positional latch for each axis.

System Elements

As shown in Fig. 1.2, the DMC-18x2 is part of a motion control system which includes amplifiers, motors and encoders. These elements are described below.

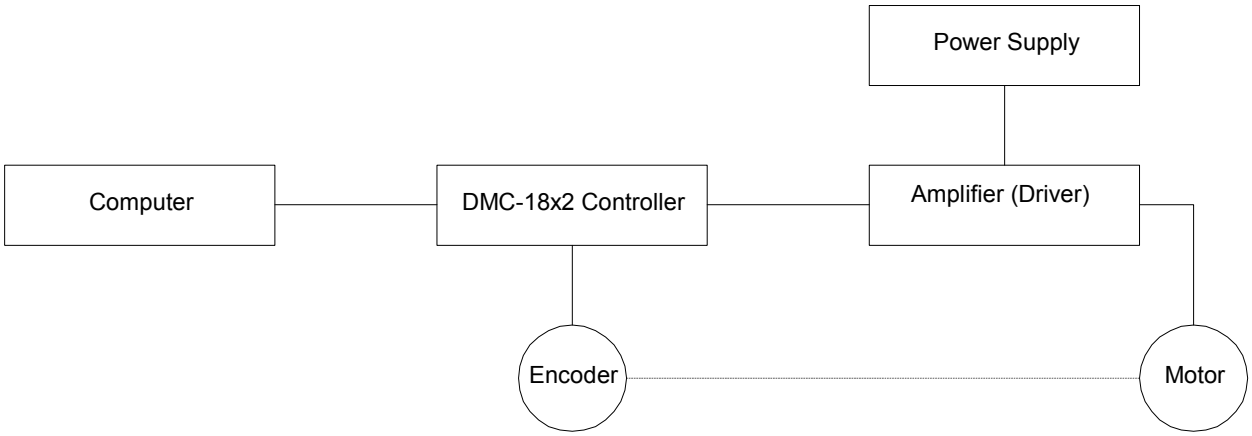

Figure 1.2 - Elements of Servo systems

Motor

A motor converts current into torque which produces motion. Each axis of motion requires a motor sized properly to move the load at the required speed and acceleration. (Galil's "Motion Component Selector" software can help you with motor sizing). Contact Galil for more information.

The motor may be a step or servo motor and can be brush-type or brushless, rotary or linear. For step motors, the controller is capable of controlling full-step, half-step, or microstep drives. An encoder is not required when step motors are used.

Amplifier (Driver)

For each axis, the power amplifier converts a +/-10 Volt signal from the controller into current to drive the motor. For stepper motors, the amplifier converts step and direction signals into current. The amplifier should be sized properly to meet the power requirements of the motor. For brushless motors, an amplifier that provides electronic commutation is required or the controller must be configured to provide sinusoidal commutation. The amplifiers may be either pulse-width-modulated (PWM) or linear. They may also be configured for operation with or without a tachometer. For current amplifiers, the amplifier gain should be set such that a 10 Volt command generates the maximum required current. For example, if the peak motor current is 10A, the amplifier gain should be 1 A/V. For velocity mode amplifiers, a 10 volt command should run the motor at the maximum speed.

Encoder

An encoder translates motion into electrical pulses which are fed back into the controller. The DMC-18x2 accepts feedback from either a rotary or linear encoder. Typical encoders provide two channels in quadrature, known as CHA and CHB. This type of encoder is known as a quadrature encoder. Quadrature encoders may be either single-ended (CHA and CHB) or differential (CHA, CHA-, CHB, CHB-). The DMC-18x2 decodes either type into quadrature states or four times the number of cycles. Encoders may also have a third channel (or index) for synchronization.

For stepper motors, the DMC-18x2 can also interface to encoders with pulse and direction signals.

There is no limit on encoder line density; however, the input frequency to the controller must not exceed 3,000,000 full encoder cycles/second (12,000,000 quadrature counts/sec). For example, if the encoder line density is 10000 cycles per inch, the maximum speed is 300 inches/second. If higher encoder frequency is required, please consult the factory.

The standard voltage level is TTL (zero to five volts), however, voltage levels up to 12 Volts are acceptable. (If using differential signals, 12 Volts can be input directly to the DMC-18x2. Single-ended 12 Volt signals require a 5-7V bias voltage input to the complementary inputs.)

The DMC-18x2 can accept analog feedback instead of an encoder for any axis. For more information see description of analog feedback in Chapter 2 under the section titled "Test the encoder operation".

To interface with other types of position sensors such as resolvers or absolute encoders, Galil can customize the controller and command set. Please contact Galil to talk to one of our applications engineers about your particular system requirements.

Watch Dog Timer

The DMC-18x2 provides an internal watch dog timer which checks for proper microprocessor operation. The timer toggles the Amplifier Enable Output (AEN), which can be used to switch the amplifiers off in the event of a serious DMC-18x2 failure. The AEN output is normally high. During power-up and if the microprocessor ceases to function properly, the AEN output will go low. The error light will also turn on at this stage. A reset is required to restore the DMC-18x2 to normal operation. Consult the factory for a Return Materials Authorization (RMA) Number if your DMC-18x2 is damaged.

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Chapter 2 Getting Started

The DMC-18x2 Motion Controller

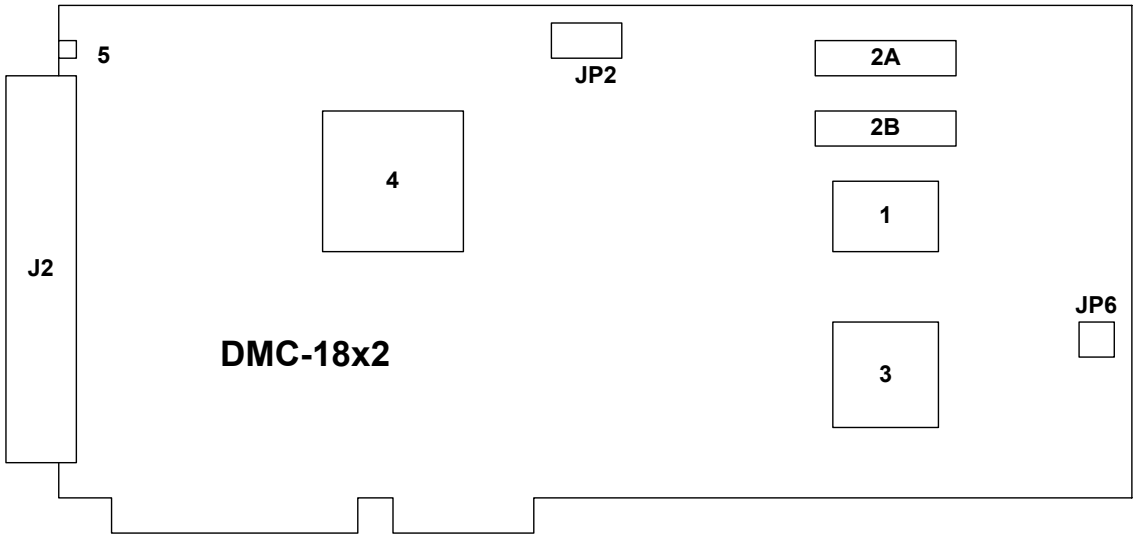

Figure 2-1 - Outline of the DMC-1812 thru DMC-1842

1	Flash EEPROM
2A/2B	RAM
3	Motorola 68331 microprocessor
4	GL-1800 custom gate array
5	Error LED
J2	100-pin high density connector (part number Amp#2-178238-9)
JP2	Jumpers used for configuring stepper motor operation *
JP6	Master Reset & UPGRD jumpers

*Install JP2 OPT jumper for default MO (Motor Off), firmware 1.0e and higher

Elements You Need

Before you start, you must get all the necessary system elements. These include:

1. DMC-1812, 1822, 1832, or DMC-1842 Motion Controller, (1) 100-pin cable, and (1) interconnect module (either ICM/AMP-1900 or ICM-2900).
2. Servo Motors with Optical Encoder (one per axis) or Stepper Motors.
3. Power Amplifiers.
4. Power Supply for Amplifiers.
5. PC (Personal Computer - PCI bus).
6. Communications Software – DMCTERM, DMCWIN32, or WSDK32 (On Galil Software CD, or download at http://www.galilmc.com/support/download.html).

The motors may be servo (brush type or brushless) or steppers. The amplifiers should be suitable for the motor and may be linear or pulse-width-modulated. An amplifier may have current feedback, voltage feedback or velocity feedback.

For servo motors in current mode, the amplifiers should accept an analog signal in the +/-10 Volt range as a command. The amplifier gain should be set such that a +10V command will generate the maximum required current. For example, if the peak motor current is 10A, the amplifier gain should be 1 A/V. For velocity mode amplifiers, a command signal of 10 Volts should run the motor at the maximum required speed. Set the velocity gain so that an input signal of 10V, runs the motor at the maximum required speed.

For step motors, the amplifiers should accept step and direction signals. For start-up of a step motor system refer to “Connecting Step Motors” on page 20.

The WSDK software is highly recommended for first time users of the DMC-18x2. It provides step-by-step instructions for system setup, tuning and analysis.

Installing the DMC-18x2

Installation of a complete, operational DMC-18x2 system consists of 9 steps.

Step 1. Determine overall motor configuration.

Step 2. Install Jumpers on the DMC-18x2.

Step 3. Install the communications software.

Step 4. Install the DMC-18x2 in the PC.

Step 5. Establish communications with the Galil communication software.

Step 6. Determine the axes to be used for sinusoidal commutation.

Step 7. Make connections to amplifier and encoder.

Step 8a. Connect standard servo motors.

Step 8b. Connect sinusoidal commutation motors.

Step 8c. Connect step motors.

Step 9. Tune the servo system.

Step 1. Determine Overall Motor Configuration

Before setting up the motion control system, the user must determine the desired motor configuration. The DMC-18x2 can control any combination of standard servo motors, sinusoidally commutated brushless motors, and stepper motors. Other types of actuators, such as hydraulics can also be controlled, please consult Galil.

The following configuration information is necessary to determine the proper motor configuration:

Standard Servo Motor Operation:

The DMC-18x2 has been setup by the factory for standard servo motor operation providing an analog command signal of +/- 10V. No hardware or software configuration is required for standard servo motor operation.

Sinusoidal Commutation:

Sinusoidal commutation is configured through a single software command, BA. This configuration causes the controller to reconfigure the number of available control axes.

Each sinusoidally commutated motor requires two DAC's. In standard servo operation, the DMC-18x2 has one DAC per axis. In order to have the additional DAC for sinusoidal commutation, the controller must be designated as having one additional axis for each sinusoidal commutation axis. For example, to control two standard servo axes and one axis of sinusoidal commutation, the controller will require a total of four DAC's and the controller must be a DMC-1842.

Sinusoidal commutation is configured with the command, BA. For example, BAX sets the X axis to be sinusoidally commutated. The second DAC for the sinusoidal signal will be the highest available DAC on the controller. For example: Using a DMC-1842, the command BAX will configure the X axis to be the main sinusoidal signal and the 'W' axis to be the second sinusoidal signal.

The BA command also reconfigures the controller to indicate that the controller has one less axis of 'standard' control for each axis of sinusoidal commutation. For example, if the command BAX is given to a DMC-1842 controller, the controller will be re-configured to a DMC-1832 controller. By definition, a DMC-1832 controls 3 axes: X, Y and Z. The 'W' axis is no longer available since the output DAC is being used for sinusoidal commutation.

Further instruction for sinusoidal commutation connections are discussed in Step 6.

Stepper Motor Operation:

To configure the DMC-18x2 for stepper motor operation, the controller requires a jumper for each stepper motor and the command, MT, must be given. The installation of the stepper motor jumper is discussed in the following section entitled "Installing Jumpers on the DMC-18x2". Further instructions for stepper motor connections are discussed in Step 8c.

Step 2. Install Jumpers on the DMC-18x2

Master Reset and Upgrade Jumpers

JP6 contains two jumpers, MRST and UPGRD. The MRST jumper is the Master Reset jumper. When MRST is connected, the controller will perform a master reset upon PC power up or upon the reset input going low. Whenever the controller has a master reset, all programs, arrays, variables, and motion control parameters stored in EEPROM will be ERASED.

The UPGRD jumper enables the user to unconditionally update the controller's firmware. This jumper is not necessary for firmware updates when the controller is operating normally, but may be necessary in cases of corrupted EEPROM. EEPROM corruption should never occur, however, it is possible if there is a power fault during a firmware update. If EEPROM corruption occurs, your controller may not operate properly. In this case, install the UPGRD Jumper and use the update firmware function on the Galil Terminal to re-load the system firmware.

Stepper Motor Jumpers

For each axis that will be used for stepper motor operation, the corresponding stepper mode (SM) jumper must be connected. The stepper mode jumpers, labeled JP2, are located directly beside the GL-1800 IC (this is the largest IC on the board - see the diagram of the DMC-18x2). The individual jumpers are labeled SMX, SMY, SMZ, and SMW and configure the controller for 'Stepper Motors' for the corresponding X, Y, Z and W axes when installed. The jumper labeled, OPT, is for use by Galil technicians only.

Step 3. Install the Communications Software

Before installing the DMC-18x2 controller in the PC, Galil communications software and drivers should be loaded. Installing the Galil software prior to installing the card will allow most operating system to automatically install the controller into both the Windows and Galil registries.

Using Win98SE, ME, NT4.0, 2000, and XP

Install the Galil Software Products CD-ROM into your CD drive. A Galil .htm page should automatically appear with links to the software products. Select "DMC-Smart Terminal", and click "Install…" Follow the installation procedure as outlined.

Using DOS:

Using the Galil Software CD-ROM, go to www.galilmc.com/support/download2.html and follow the instructions.

Note: Galil software is also available for download at: http://www.galilmc.com/support/download.html

Step 4. Install the DMC-18x2 in the PC

The DMC-18x2 is installed directly into the **PCI** expansion bus. The procedure is outlined below.

Step A. Make sure the PC is in the power-off condition.

Step B. Remove unit cover.

Step C. Remove the metal plate covering the expansion bus slot where the DMC-18x2 will be inserted.

Step D. Insert DMC-18x2 card in the expansion bus and secure with screw.

Step E. Attach 100-pin cable to your controller card. If you are using a Galil ICM-1900, AMP-19X0, or ICM-2900, this cable connects into the J2 connection on the interconnect module. If you are not using a Galil interconnect module, you will need to appropriately terminate the cable to your system components, see the appendix for cable pin outs.

After turning on the power to the computer, your computer should recognize the DMC-18x2 as a new device and will automatically install the device into the Windows and Galil registries.

Step 5. Establish Communication using Galil Software

Using Win98SE, ME, NT4.0, 2000, and XP

When DMC Smart Terminal is executed, it will automatically attempt communication if you have only 1 controller entry in the registry. If more than one controller is installed or registered, a prompt will appear where you can select the controller by highlighting it. Once the entry has been selected, click on the **OK** button. If communication is established with the controller, the terminal window will open and a colon prompt will be displayed. From the top line of the terminal, you can send commands to the controller. Command syntax is described in later sections and the Command Reference.

If you are not properly communicating with the controller, the program will pause for 3-15 seconds. The top of the screen will display the message "Status: not connected with Galil motion controller" and the following error will appear: "STOP - Unable to establish communication with the Galil controller. A time-out occurred while waiting for a response from the Galil controller." If this message appears, you must click OK. Contact Galil if you are unable to communicate with your controller.

Dos Users:

The installation of DMCDOS from the Galil software CD will install the program DMCTERM, an interactive communication program. When running DMCTERM, you will have to provide:

1) The communication address
2) The IRQ number if one is used

After providing the setup information, the terminal display should show a colon, : . If you do not receive a colon, the computer does not recognize your 18x2 controller.

Our DOS utilities accept command line arguments. To use these utilities with the 1802 controller, include the argument -c1802. For a complete list of command line arguments, type the utility name with a "?" as an argument (Ex. SEND2DMC ?).

Consult the factory if you need help.

Step 6. Determine the Axes to be Used for Sinusoidal Commutation

* This step is only required when the controller will be used to control brushless motors with sinusoidal commutation.

The command BA is used to select the axes of sinusoidal commutation. For example, BAXY sets X and Y as axes with sinusoidal commutation. With the DMC-18X2, at most 2 axes can be set for sinusoidal commutation, requiring a DMC-1842.

Notes on Configuring Sinusoidal Commutation:

The command, BA, reconfigures the controller such that it has one less axis of 'standard' control for every axis using sinusoidal commutation. For example, if the command BAX is given to a DMC-1842 controller, the controller will be re-configured to be a DMC-1832 and will appear as such when interrogated. In this case the highest axis is used for the 2nd phase of the sinusoidal commutation and cannot be connected to control a separate motor. Note that the highest axis on a controller can never be configured for sinusoidal commutation.

The DAC associated with the selected axis represents the first phase. The second phase uses the highest available DAC. When two axes are configured for sinusoidal commutation, the controller will assign the X and Z axes DAC's for the first and second phase of the X axis' commutation respectively and the Y and W axes DAC's for the first and second phase of the Y axis' commutation respectively. The highest sinusoidal commutation axis will be assigned to the highest available DAC and the lowest sinusoidal commutation axis will be assigned to the lowest available DAC.

Step 7. Make Connections to Amplifier and Encoder.

Once you have established communication between the software and the DMC-18x2, you are ready to connect the rest of the motion control system. The motion control system typically consists of an interconnect module (ICM-1900 or ICM-2900), an amplifier for each axis of motion, and a motor to transform the current from the amplifier into torque for motion. Galil also offers the AMP-19X0 which is an ICM-1900 equipped with X number servo amplifiers for brush type DC motors.

If you are using an ICM/AMP-1900 or ICM-2900, connect the 100-pin cable to the DMC-18x2 and to the connector located on the interconnect board. The interconnect provides screw terminals for access to the 100-pin connections.

System connection procedures will depend on system components and motor types. Any combination of motor types can be used with the DMC-18x2. If sinusoidal commutation is to be used, special attention must be paid to the reconfiguration of axes.

Here are the first steps for connecting a motion control system:

Step A. Connect the motor to the amplifier *with no connection to the controller*. Consult the amplifier documentation for proper instructions. Connect and turn-on the amplifier power supply. If the amplifiers are operating properly, the motor should stand still even when the amplifiers are powered up.

Step B. Connect the amplifier enable signal.

Before making any connections from the amplifier to the controller, you need to verify that the ground level of the amplifier is either floating or at the same potential as earth.

WARNING: When the amplifier ground is not isolated from the power line or when it has a different potential than that of the computer ground, serious damage may result to the computer, controller, and amplifier.

If you are not sure about the potential of the ground levels, connect the two ground signals (amplifier ground and earth) by a 10 KΩ resistor and measure the voltage across the resistor. Only if the voltage is zero, connect the two ground signals directly.

The amplifier enable signal (AEN) is used by the controller to disable the motor. This signal is labeled AMPENX for the X axis on the interconnect board and should be connected to the enable signal on the amplifier. Note that many amplifiers designate this signal as the INHIBIT signal. Use the command, MO, to disable the motor amplifiers - check to insure that the motor amplifiers have been disabled (often this is indicated by an LED on the amplifier).

This signal changes under the following conditions: the watchdog timer activates, the motor-off command, MO, is given, or the OE1 command (Enable Off-On-Error) is given

and the position error exceeds the error limit. As shown in Figure 3-4, AEN can be used to disable the amplifier for these conditions.

The standard configuration of the AEN signal is TTL active high. In other words, the AEN signal will be high when the controller expects the amplifier to be enabled. The polarity and the amplitude can be changed if you are using the ICM/AMP-1900 or ICM-2900. To change the polarity from active high (5 volts = enable, zero volts = disable) to active low (zero volts = enable, 5 volts = disable), replace the 7407 IC with a 7406. Note that many amplifiers designate the enable input as 'inhibit'.

To change the voltage level of the AEN signal, note the state of the resistor pack on the interconnect module. When Pin 1 is on the 5V mark, the output voltage is 0-5V. To change to 12 volts, pull the resistor pack and rotate it so that Pin 1 is on the 12 volt side. If you remove the resistor pack, the output signal is an open collector, allowing the user to connect an external supply with voltages up to 24V. To do this, pull the resistor pack. Then connect the power supply +24V to the AEN connector on the ICM. A resistor is placed in line to limit the current to 10mA.

Step C. Connect the encoders

For stepper motor operation, an encoder is optional.

For servo motor operation, if you have a preferred definition of the forward and reverse directions, make sure that the encoder wiring is consistent with that definition.

The DMC-18x2 accepts single-ended or differential encoder feedback with or without an index pulse. If you are not using the AMP-19x0 or the ICM-1900 you will need to consult the appendix for the encoder pinouts for connection to the motion controller. The AMP-19x0 and the ICM-1900 can accept encoder feedback from a 10-pin ribbon cable or individual signal leads. For a 10-pin ribbon cable encoder, connect the cable to the protected header connector labeled X ENCODER (repeat for each axis necessary). For individual wires, simply match the leads from the encoder you are using to the encoder feedback inputs on the interconnect board. The signal leads are labeled CHA (channel A), CHB (channel B), and INDEX. For differential encoders, the complement signals are labeled CHA-, CHB-, and INDEX-.

Note: When using pulse and direction encoders, the pulse signal is connected to CHA and the direction signal is connected to CHB. The controller must be configured for pulse and direction with the command CE. See the command summary for further information on the command CE.

Step D. Verify proper encoder operation.

Start with the X encoder first. Once it is connected, turn the motor shaft and interrogate the position with the instruction TPX <return>. The controller response will vary as the motor is turned.

At this point, if TPX does not vary with encoder rotation, there are three possibilities:

1. The encoder connections are incorrect - check the wiring as necessary.
2. The encoder has failed - using an oscilloscope, observe the encoder signals. Verify that both channels A and B have a peak magnitude between 5 and 12 volts. Note that if only one encoder channel fails, the position reporting varies by one count only. If the encoder failed, replace the encoder. If you cannot observe the encoder signals, try a different encoder.
3. There is a hardware failure in the controller - connect the same encoder to a different axis. If the problem disappears, you probably have a hardware failure. Consult the factory for help.

Step E. Connect Hall Sensors if available.

Hall sensors are only used with sinusoidal commutation and are not necessary for proper operation. The use of hall sensors allows the controller to automatically estimate the commutation phase upon reset and also provides the controller the ability to set a more precise commutation phase. Without hall sensors, the commutation phase must be determined manually.

Each set of sensors must use inputs that are in consecutive order. The input lines are specified with the command, BI. For example, if the Hall sensors of the Z axis are connected to inputs 6, 7 and 8, use the instruction:

BI ,, 6

or

BIZ = 6

Step 8a. Connect Standard Servo Motors

The following discussion applies to connecting the DMC-18x2 controller to standard servo motor amplifiers:

The motor and the amplifier may be configured in the torque or the velocity mode. In the torque mode, the amplifier gain should be such that a 10 Volt signal generates the maximum required current. In the velocity mode, a command signal of 10 Volts should run the motor at the maximum required speed.

Step by step directions on servo system setup are also included on the WSDK (Windows Servo Design Kit) software offered by Galil. See section on WSDK for more details.

Step A. Check the Polarity of the Feedback Loop

It is assumed that the motor and amplifier are connected together and that the encoder is operating correctly (Step B). Before connecting the motor amplifiers to the controller, read the following discussion on setting Error Limits and Torque Limits. Note that this discussion only uses the X axis as an example.

Step B. Set the Error Limit as a Safety Precaution

Usually, there is uncertainty about the correct polarity of the feedback. The wrong polarity causes the motor to run away from the starting position. Using a terminal program, such as DMCTERM, the following parameters can be given to avoid system damage:

Input the commands:

ER 2000 <CR> Sets error limit on the X axis to be 2000 encoder counts

OE 1 <CR> Disables X axis amplifier when excess position error exists

If the motor runs away and creates a position error of 2000 counts, the motor amplifier will be disabled. **Note:** This function requires the AEN signal to be connected from the controller to the amplifier.

Step C. Set Torque Limit as a Safety Precaution

To limit the maximum voltage signal to your amplifier, the DMC-18x2 controller has a torque limit command, TL. This command sets the maximum voltage output of the controller and can be used to avoid excessive torque or speed when initially setting up a servo system.

When operating an amplifier in torque mode, the voltage output of the controller will be directly related to the torque output of the motor. The user is responsible for determining this relationship using the documentation of the motor and amplifier. The torque limit can be set to a value that will limit the output torque of the motor.

When operating an amplifier in velocity or voltage mode, the voltage output of the controller will be directly related to the velocity of the motor. The user is responsible for determining this relationship using the documentation of the motor and amplifier. The torque limit can be set to a value that will limit the speed of the motor.

For example, the following command will limit the output of the controller to 1 volt on the X axis:

TL 1 <CR>

Note: Once the correct polarity of the feedback loop has been determined, the torque limit should, in general, be increased to the default value of 9.99. The servo will not operate properly if the torque limit is below the normal operating range. See description of TL in the command reference.

Step D. Connect the Motor

Once the parameters have been set, connect the analog motor command signal (ACMD) to the amplifier input.

To test the polarity of the feedback, command a move with the instruction:

PR 1000 <CR> Position relative 1000 counts

BGX <CR> Begin motion on X axis

When the polarity of the feedback is wrong, the motor will attempt to run away. The controller should disable the motor when the position error exceeds 2000 counts. If the motor runs away, the polarity of the loop must be inverted.

Inverting the Loop Polarity

When the polarity of the feedback is incorrect, the user must invert the loop polarity and this may be accomplished by several methods. If you are driving a brush-type DC motor, the simplest way is to invert the two motor wires (typically red and black). For example, switch the M1 and M2 connections going from your amplifier to the motor. When driving a brushless motor, the polarity reversal may be done with the encoder. If you are using a single-ended encoder, interchange the signal CHA and CHB. If, on the other hand, you are using a differential encoder, interchange only CHA+ and CHA-. The loop polarity and encoder polarity can also be affected through software with the MT and CE commands, respectively. For more details on the MT command or the CE command, see the Command Reference section.

Sometimes the feedback polarity is correct (the motor does not attempt to run away) but the direction of motion is reversed with respect to the desired commanded motion. If this is the case, reverse the motor leads AND the encoder signals.

If the motor moves in the required direction but stops short of the target, it is most likely due to insufficient torque output from the motor command signal ACMD. This can be alleviated by reducing system friction on the motors. The instruction:

TTX (CR) Tell torque on X

reports the level of the output signal. It will show a non-zero value that is below the friction level.

Once you have established that you have closed the loop with the correct polarity, you can move on to the compensation phase (servo system tuning) to adjust the PID filter parameters, KP, KD and KI. It is necessary to accurately tune your servo system to ensure fidelity of position and minimize motion oscillation as described in the next section.

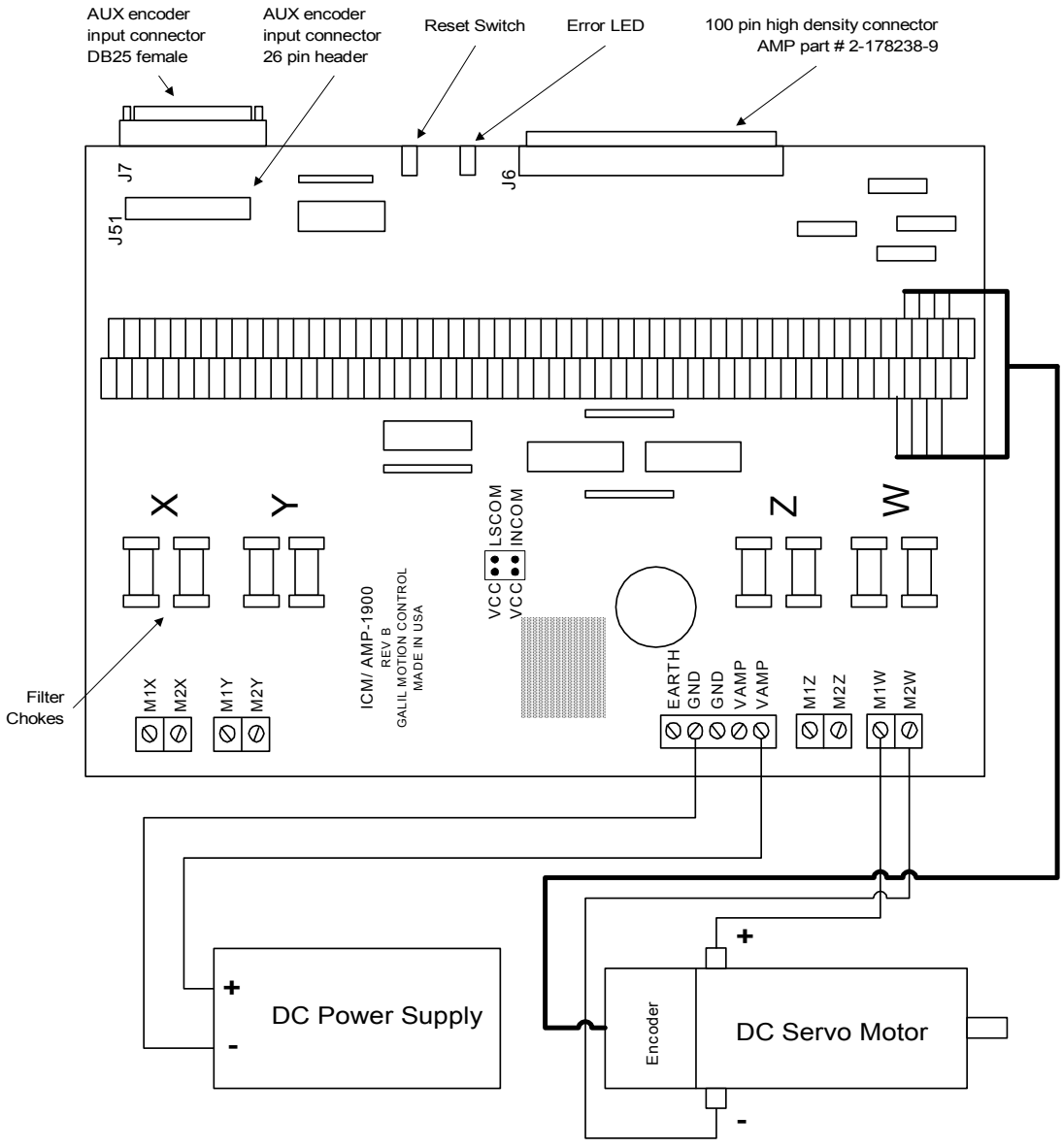

Figure 2-2 - System Connections with the AMP-1900 Amplifier. Note: this figure shows a Galil Motor and Encoder which uses a flat ribbon cable for connection to the AMP-1900 unit.

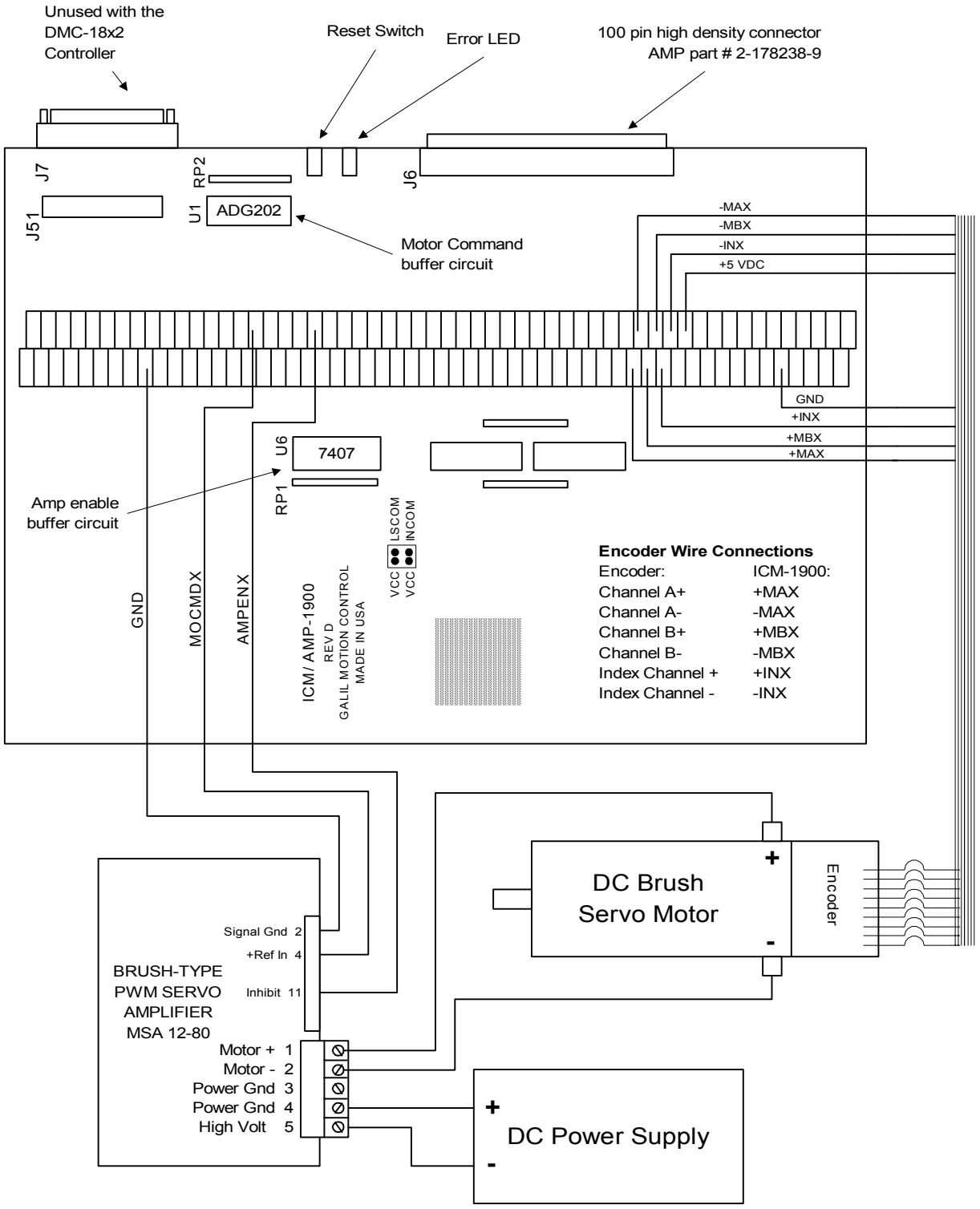

Figure 2-3 System Connections with a separate amplifier (MSA 12-80). This diagram shows the connections for a standard DC Servo Motor and encoder

Step 8b. Connect Sinusoidal Commutation Motors

When using sinusoidal commutation, the parameters for the commutation must be determined and saved in the controller's non-volatile memory. The servo can then be tuned as described in Step 9.

Step A. Disable the motor amplifier

Use the command, MO, to disable the motor amplifiers. For example, MOX will turn the X axis motor off.

Step B. Connect the motor amplifier to the controller.

The sinusoidal commutation amplifier requires 2 signals, usually denoted as Phase A & Phase B. These inputs should be connected to the two sinusoidal signals generated by the controller. The first signal is the axis specified with the command, BA (Step 6). The second signal is associated with the highest analog command signal available on the controller - note that this axis was made unavailable for standard servo operation by the command BA.

When more than one axis is configured for sinusoidal commutation, the controller will assign the second phase to the command output which has been made available through the axes reconfiguration. The 2nd phase of the highest sinusoidal commutation axis will be the highest command output and the 2nd phase of the lowest sinusoidal commutation axis will be the lowest command output.

It is not necessary to be concerned with cross-wiring the 1st and 2nd signals. If this wiring is incorrect, the setup procedure will alert the user (Step D).

Example: Sinusoidal Commutation Configuration using a DMC-1842

BAXY

This command causes the controller to be reconfigured as a DMC-1822 controller. The X and Y axes are configured for sinusoidal commutation. The first phase of the X axis will be the motor command Z signal. The second phase of the X axis will be the motor command Z signal. The first phase of the axis will be the motor Y command Y signal. The second phase of the Y axis will be the motor command W signal.

Step C. Specify the Size of the Magnetic Cycle.

Use the command, BM, to specify the size of the brushless motors magnetic cycle in encoder counts. For example, if the X axis is a linear motor where the magnetic cycle length is 62 mm, and the encoder resolution is 1 micron, the cycle equals 62,000 counts. This can be commanded with the command:

BM 62000

On the other hand, if the Z axis is a rotary motor with 4000 counts per revolution and 3 magnetic cycles per revolution (three pole pairs) the command is

BM,, 1333.333

Step D. Test the Polarity of the DACs and Hall Sensor Configuration.

Use the brushless motor setup command, BS, to test the polarity of the output DACs. This command applies a certain voltage, V, to each phase for some time T, and checks to see if the motion is in the correct direction.

The user must specify the value for V and T. For example, the command

BSX = 2,700

will test the X axis with a voltage of 2 volts, applying it for 700 millisecond for each phase. In response, this test indicates whether the DAC wiring is correct and will indicate an approximate value of BM. If the wiring is correct, the approximate value for BM will agree with the value used in the previous step.

Note: In order to properly conduct the brushless setup, the motor must be allowed to move a minimum of one magnetic cycle in both directions.

Note: When using Galil Windows software, the timeout must be set to a minimum of 10 seconds (time-out = 10000) when executing the BS command. This allows the software to retrieve all messages returned from the controller.

If Hall Sensors are Available:

Since the Hall sensors are connected randomly, it is very likely that they are wired in the incorrect order. The brushless setup command indicates the correct wiring of the Hall sensors. The hall sensor wires should be re-configured to reflect the results of this test.

The setup command also reports the position offset of the hall transition point and the zero phase of the motor commutation. The zero transition of the Hall sensors typically occur at 0°, 30° or 90° of the phase commutation. It is necessary to inform the controller about the offset of the Hall sensor and this is done with the instruction, BB.

Step E. Save Brushless Motor Configuration

It is very important to save the brushless motor configuration in non-volatile memory. After the motor wiring and setup parameters have been properly configured, the burn command, BN, should be given.

If Hall Sensors are Not Available:

Without hall sensors, the controller will not be able to estimate the commutation phase of the brushless motor. In this case, the controller could become unstable until the commutation phase has been set using the BZ command (see next step). It is highly recommended that the motor off command be given before executing the BN command. In this case, the motor will be disabled upon power up or reset and the commutation phase can be set before enabling the motor.

Step F. Set Zero Commutation Phase

When an axis has been defined as sinusoidally commutated, the controller must have an estimate for commutation phase. When hall sensors are used, the controller automatically estimates this value upon reset of the controller. If no hall sensors are used, the controller will not be able to make this estimate and the commutation phase must be set before enabling the motor.

If Hall Sensors are Not Available:

To initialize the commutation without Hall effect sensor use the command, BZ. This function drives the motor to a position where the commutation phase is zero, and sets the phase to zero.

The BZ command is followed by real numbers in the fields corresponding to the driven axes. The number represents the voltage to be applied to the amplifier during the initialization. When the voltage is specified by a positive number, the initialization process ends up in the motor off (MO) state. A negative number causes the process to end in the Servo Here (SH) state.

Warning: This command must move the motor to find the zero commutation phase. This movement is instantaneous and will cause the system to jerk. Larger applied voltages will cause more severe motor jerk. The applied voltage will typically be

sufficient for proper operation of the BZ command. For systems with significant friction, this voltage may need to be increased and for systems with very small motors, this value should be decreased.

For example,

BZ -2, 0, 1

will drive both X and Z axes to zero, will apply 2V and 1V respectively to X and Z and will end up with X in SH and Z in MO.

If Hall Sensors are Available:

The estimated value of the commutation phase is good to within 30°. This estimate can be used to drive the motor but a more accurate estimate is needed for efficient motor operation. There are 3 possible methods for commutation phase initialization:

Method 1. Use the BZ command as described above.

Method 2. Drive the motor close to commutation phase of zero and then use BZ command. This method decreases the amount of system jerk by moving the motor close to zero commutation phase before executing the BZ command. The controller makes an estimate for the number of encoder counts between the current position and the position of zero commutation phase. This value is stored in the operand _BZx. Using this operand the controller can be commanded to move the motor. The BZ command is then issued as described above. For example, to initialize the X axis motor upon power or reset, the following commands may be given:

```
SHX                 ;Enable X axis motor
PRX=-1*(_BZX)       ;Move X motor close to zero commutation phase
BGX                 ;Begin motion on X axis
AMX                 ;Wait for motion to complete on X axis
BZX=-1              ;Drive motor to commutation phase zero and leave
                    ;motor on
```

Method 3. Use the command, BC. This command uses the hall transitions to determine the commutation phase. Ideally, the hall sensor transitions will be separated by exactly 60° and any deviation from 60° will affect the accuracy of this method. If the hall sensors are accurate, this method is recommended. The BC command monitors the hall sensors during a move and monitors the Hall sensors for a transition point. When that occurs, the controller computes the commutation phase and sets it. For example, to initialize the X axis motor upon power or reset, the following commands may be given:

```
SHX                 ;Enable X axis motor
BCX                 ;Enable the brushless calibration command
PRX=50000           ;Command a relative position movement on X axis
BGX                 ;Begin motion on X axis. When the hall sensors
                    ; detect a phase transition, the commutation phase is
                    ;re-set.
```

Step 8C. Connect Step Motors

In Stepper Motor operation, the pulse output signal has a 50% duty cycle. Step motors operate open loop and do not require encoder feedback. When a stepper is used, the auxiliary encoder for the

corresponding axis is unavailable for an external connection. If an encoder is used for position feedback, connect the encoder to the main encoder input corresponding to that axis. The commanded position of the stepper can be interrogated with RP or DE. The encoder position can be interrogated with TP.

The frequency of the step motor pulses can be smoothed with the filter parameter, KS. The KS parameter has a range between 0.5 and 16, where 16 implies the largest amount of smoothing. *See Command Reference regarding KS.*

The DMC-18x2 profiler commands the step motor amplifier. All DMC-18x2 motion commands apply such as PR, PA, VP, CR and JG. The acceleration, deceleration, slew speed and smoothing are also used. Since step motors run open-loop, the PID filter does not function and the position error is not generated.

To connect step motors with the DMC-18x2 you must follow this procedure:

Step A. Install SM jumpers

Each axis of the DMC-18x2 that will operate a stepper motor must have the corresponding stepper motor jumper installed. For a discussion of SM jumpers, see section *Step* 2. Install Jumpers on the DMC-18x2.

Step B. Connect step and direction signals from controller to motor amplifier

from the controller to respective signals on your step motor amplifier. (These signals are labeled PWMX and SIGNX for the x-axis on the ICM-2900). Consult the documentation for your step motor amplifier.

Step C. Configure DMC-18x2 for motor type using MT command. You can configure the DMC-18x2 for active high or active low pulses. Use the command MT 2 for active low step motor pulses and MT -2 for active high step motor pulses. *See description of the MT command in the Command Reference.*

Step 9. Tune the Servo System

Adjusting the tuning parameters is required when using servo motors (standard or sinusoidal commutation). The system compensation provides fast and accurate response and the following presentation suggests a simple and easy way for compensation. More advanced design methods are available with software design tools from Galil, such as the Servo Design Kit (SDK software)

The filter has three parameters: the damping, KD; the proportional gain, KP; and the integrator, KI. The parameters should be selected in this order.

To start, set the integrator to zero with the instruction

KI 0 (CR) Integrator gain

and set the proportional gain to a low value, such as

KP 1 (CR) Proportional gain

KD 100 (CR) Derivative gain

For more damping, you can increase KD (maximum is 4095). Increase gradually and stop after the motor vibrates. A vibration is noticed by audible sound or by interrogation. If you send the command

TE X (CR) Tell error

a few times, and get varying responses, especially with reversing polarity, it indicates system vibration. When this happens, simply reduce KD.

Next you need to increase the value of KP gradually (maximum allowed is 1023). You can monitor the improvement in the response with the Tell Error instruction

KP 10 (CR) Proportion gain

TE X (CR) Tell error

As the proportional gain is increased, the error decreases.

Again, the system may vibrate if the gain is too high. In this case, reduce KP. Typically, KP should not be greater than KD/4. (Only when the amplifier is configured in the current mode).

Finally, to select KI, start with zero value and increase it gradually. The integrator eliminates the position error, resulting in improved accuracy. Therefore, the response to the instruction

TE X (CR)

becomes zero. As KI is increased, its effect is amplified and it may lead to vibrations. If this occurs, simply reduce KI. Repeat tuning for the Y, Z and W axes.

For a more detailed description of the operation of the PID filter and/or servo system theory, see Chapter 10 - Theory of Operation.

Design Examples

Here are a few examples for tuning and using your controller. These examples have remarks next to each command - these remarks must not be included in the actual program.

Example 1 - System Set-up

This example assigns the system filter parameters, error limits and enables the automatic error shut-off.

Instruction	Interpretation
KP10,10,10,10	Set gains for a,b,c,d (or X,Y,Z,W axes)
KP*=10	Alternate method for setting gain on all axes
KPX=10	Alternate method for setting X (or A) axis gain
KPA=10	Alternate method for setting A (or X) axis gain
KP, 20	Set Y axis gain only
ER*=1000	Set error limit for all axes to 1000 counts
OE1,1,1,1	Enable automatic off on error function for all 4 axes

Example 2 – Profiled Move

Objective: Rotate the X axis a distance of 10,000 counts at a slew speed of 20,000 counts/sec and acceleration and deceleration rates of 100,000 counts/s^2 . In this example, the motor turns and stops:

Instruction	Interpretation
PR10000	Distance
SP20000	Speed
AC100000	Acceleration
DC100000	Deceleration
BGX	Start Motion

Example 3 – Multiple Axes

Objective: Move the four axes independently.

Instruction	Interpretation
PR 500,1000,600,-400	Distances of X,Y,Z,W
SP 10000,12000,20000,10000	Slew speeds of X,Y,Z,W
AC 100000,10000,100000,100000	Accelerations of X,Y,Z,W
DC 80000,40000,30000,50000	Decelerations of X,Y,Z,W
BG XZ	Start X and Z motion
BG YW	Start Y and W motion

Example 4 - Independent Moves

The motion parameters may be specified independently as illustrated below.

Instruction	Interpretation
PR ,300,-600	Distances of Y and Z
SP ,2000	Slew speed of Y
DC ,80000	Deceleration of Y
AC, 100000	Acceleration of Y
SP ,,40000	Slew speed of Z
AC ,,100000	Acceleration of Z
DC ,,150000	Deceleration of Z
BG Z	Start Z motion
BG Y	Start Y motion

Example 5 - Position Interrogation

The position of the four axes may be interrogated with the instruction, TP.

Instruction	Interpretation
TP	Tell position all four axes
TP X	Tell position - X axis only
TP Y	Tell position - Y axis only
TP Z	Tell position - Z axis only
TP W	Tell position - W axis only

The position error, which is the difference between the commanded position and the actual position can be interrogated with the instruction TE.

Instruction	Interpretation
TE	Tell error - all axes
TE X	Tell error - X axis only
TE Y	Tell error - Y axis only
TE Z	Tell error - Z axis only
TE W	Tell error - W axis only

Example 6 - Absolute Position

Objective: Command motion by specifying the absolute position.

Instruction	Interpretation
DP 0,2000	Define the current positions of X,Y as 0 and 2000

PA 7000,4000	Sets the desired absolute positions
BG X	Start X motion
BG Y	Start Y motion

After both motions are complete, the X and Y axes can be command back to zero:

PA 0,0	Move to 0,0
BG XY	Start both motions

Example 7 - Velocity Control

Objective: Drive the X and Y motors at specified speeds.

Instruction	Interpretation
JG 10000,-20000	Set Jog Speeds and Directions
AC 100000, 40000	Set accelerations
DC 50000,50000	Set decelerations
BG XY	Start motion

after a few seconds, command:

JG -40000	New X speed and Direction
TV X	Returns X speed

and then

JG ,20000	New Y speed
TV Y	Returns Y speed

These cause velocity changes including direction reversal. The motion can be stopped with the instruction

ST	Stop

Example 8 - Operation Under Torque Limit

The magnitude of the motor command may be limited independently by the instruction TL.

Instruction	Interpretation
TL 0.2	Set output limit of X axis to 0.2 volts
JG 10000	Set X speed
BG X	Start X motion

In this example, the X motor will probably not move since the output signal will not be sufficient to overcome the friction. If the motion starts, it can be stopped easily by a touch of a finger.

Note: Response is determined by the gain of the amplifier

Increase the torque level gradually by instructions such as

Instruction	Interpretation
TL 1.0	Increase torque limit to 1 volt.
TL 9.98	Increase torque limit to maximum, 9.98 Volts.

The maximum level of 9.998 volts provides the full output torque.

Example 9 - Interrogation

The values of the parameters may be interrogated. Some examples …

Instruction	Interpretation
KP ?	Return gain of X axis.
KP ,,?	Return gain of Z axis.
KP ?,?,?,?	Return gains of all axes.

Many other parameters such as KI, KD, FA, can also be interrogated. The command reference denotes all commands that can be interrogated.

Example 10 - Operation in the Buffer Mode

The instructions may be buffered before execution as shown below.

Instruction	Interpretation
PR 600000	Distance
SP 10000	Speed
WT 10000	Wait 10000 milliseconds before reading the next instruction
BG X	Start the motion

Example 11 - Using the On-Board Editor

Motion programs may be edited and stored in the controller memory. They may be executed at a later time. If the Smart Terminal is opened in the 3-pane view, then programs can be entered, edited and downloaded from the window on the right side. The editor window has a file and edit menu within the pane. The upload or download options are found in the file menu.

Instruction	Interpretation
#A	Define label
PR 700	Distance
SP 2000	Speed
BGX	Start X motion
EN	End program

This program can be downloaded to the controller by selecting Download from the File menu. Once this is done, close the editor. Now the program may be executed with the command

XQ #A	Start the program running

Example 12 - Motion Programs with Loops

Motion programs may include conditional jumps as shown below.

Instruction	Interpretation
#A	Label
DP 0	Define current position as zero
V1=1000	Set initial value of V1
#LOOP	Label for loop
PA V1	Move X motor V1 counts
BG X	Start X motion
AM X	After X motion is complete
WT 500	Wait 500 ms
TP X	Tell position X
V1=V1+1000	Increase the value of V1
JP #LOOP,V1<10001	Repeat if V1<10001
EN	End

After the above program is entered and downloaded to the controller, start the motion with the command:

XQ #A	Execute Program #A

Example 13 - Motion Programs with Trippoints

The motion programs may include trippoints as shown below.

Instruction	Interpretation
#B	Label
DP 0,0	Define initial positions
PR 30000,60000	Set targets
SP 5000,5000	Set speeds
BGX	Start X motion
AD 4000	Wait until X moved 4000
BGY	Start Y motion
AP 6000	Wait until position X=6000
SP 2000,50000	Change speeds
AP ,50000	Wait until position Y=50000
SP ,10000	Change speed of Y
EN	End program

To start the program, command:

XQ #B	Execute Program #B

Example 14 - Control Variables

Objective: To show how control variables may be utilized.

Instruction	Interpretation
#A;DP0	Label; Define current position as zero
PR 4000	Initial position

SP 2000	Set speed
BGX	Move X
AMX	Wait until move is complete
WT 500	Wait 500 ms
#B	
V1 = _TPX	Determine distance to zero
PR -V1/2	Command X move 1/2 the distance
BGX	Start X motion
AMX	After X moved
WT 500	Wait 500 ms
V1=	Report the value of V1
JP #C, V1=0	Exit if position=0
JP #B	Repeat otherwise
#C	Label #C
EN	End of Program

To start the program, command

XQ #A	Execute Program #A

This program moves X to an initial position of 1000 and returns it to zero on increments of half the distance. Note, _TPX is an internal variable which returns the value of the X position. Variables may be created by preceding a DMC-18x2 instruction with an underscore. For example, UI=_TPX.

Example 15 - Linear Interpolation

Objective: Move X,Y,Z motors distance of 7000,3000,6000, respectively, along linear trajectory. Namely, motors start and stop together.

Instruction	Interpretation
LM XYZ	Specify linear interpolation axes
LI 7000,3000,6000	Relative distances for linear interpolation
LE	Linear End
VS 6000	Vector speed
VA 20000	Vector acceleration
VD 20000	Vector deceleration
BGS	Start motion

Example 16 - Circular Interpolation

Objective: Move the XY axes in circular mode to form the path shown on Fig. 2-4. Note that the vector motion starts at a local position (0,0) which is defined at the beginning of any vector motion sequence. See application programming for further information.

Instruction	Interpretation
VM XY	Select XY axes for circular interpolation
VP -4000,0	Linear segment
CR 2000,270,-180	Circular segment
VP 0,4000	Linear segment
CR 2000,90,-180	Circular segment
VS 1000	Vector speed

VA 50000	Vector acceleration
VD 50000	Vector deceleration
VE	End vector sequence
BGS	Start motion

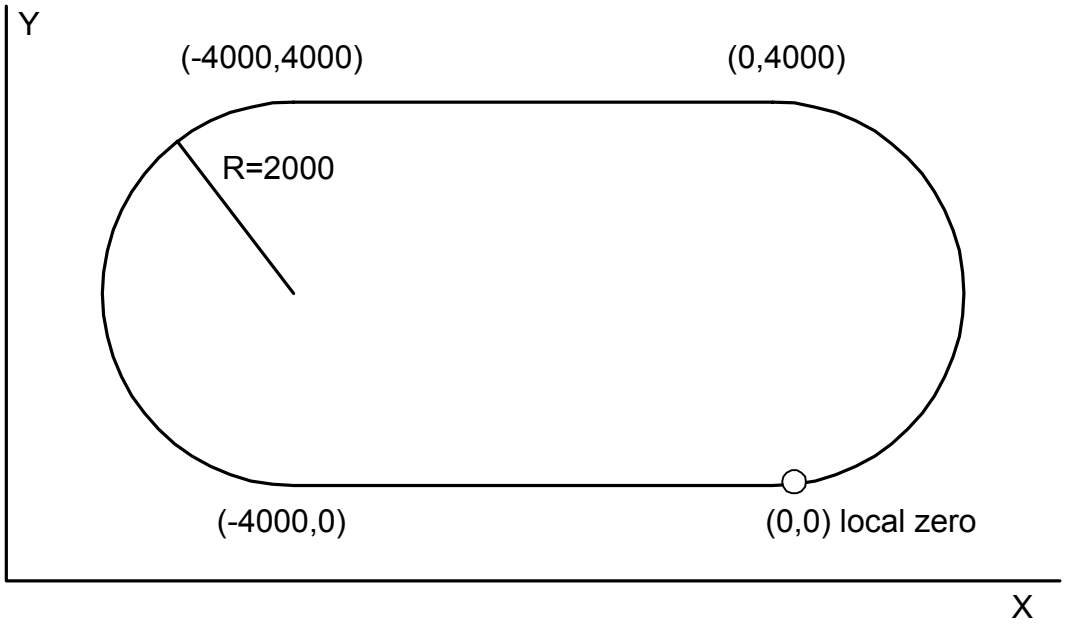

Figure 2-4 Motion Path for Example 16

Chapter 3 Connecting Hardware

Overview

The DMC-18x2 provides digital inputs for **forward limit**, **reverse limit, home**, and **abort** signals. The controller also has **8 uncommitted, TTL inputs (**for general use) as well as **8 TTL outputs**.

This chapter describes the inputs and outputs and their proper connection.

Using Inputs

Limit Switch Input

The forward limit switch (FLSx) inhibits motion in the forward direction immediately upon activation of the switch. The reverse limit switch (RLSx) inhibits motion in the reverse direction immediately upon activation of the switch. If a limit switch is activated during motion, the controller will make a decelerated stop using the deceleration rate previously set with the DC command. The motor will remain on (in a servo state) after the limit switch has been activated and will hold motor position. To set the activation state of the limit switches refer to the command CN, configure, in the Command Reference.

When a forward or reverse limit switch is activated, the current application program that is running will be interrupted and the controller will automatically jump to the #LIMSWI subroutine if one exists. This is a subroutine which the user can include in any motion control program and is useful for executing specific instructions upon activation of a limit switch.

After a limit switch has been activated, further motion in the direction of the limit switch will not be possible until the logic state of the switch returns back to an inactive state. This usually involves physically opening the tripped switch. Any attempt at further motion before the logic state has been reset will result in the following error: “022 - Begin not possible due to limit switch” error.

The operands, _LFx and _LRx, return the state of the forward and reverse limit switches, respectively (x represents the axis, X,Y,Z, or W). The value of the operand is either a ‘0’ or ‘1’ corresponding to the logic state of the limit switch, active or inactive, respectively. If the limit switches are configured for active low, no connection or a 5V input will be read as a ‘0’, while grounding the switch will return a ‘1’. If the limit switches are configured for active high, the reading will be inverted and no connection or a 5V input will be read as a ‘1’, while grounding the switch will return a ‘0’. (See the CN command in the Command Reference for details).

Using a terminal program, the state of a limit switch can be printed to the screen with the command, MG _LFx or MG _LRx. This prints the value of the limit switch operands for the 'x' axis. The logic

state of the limit switches can also be interrogated with the TS command. For more details on TS, _LFx, _LRx, or MG see the Command Reference.

Home Switch Input

Homing inputs are designed to provide mechanical reference points for a motion control application. A transition in the state of a Home input alerts the controller that a particular reference point has been reached by a moving part in the motion control system. A reference point can be a point in space or an encoder index pulse.

The Home input detects any transition in the state of the switch and changes between logic states 0 and 1, corresponding to either 0V or 5V depending on the configuration set by the user (CN command). The CN command can be used to customize the homing routine to the user's application.

There are three homing routines supported by the DMC-18x2: Find Edge (FE), Find Index (FI), and Standard Home (HM).

The Find Edge routine is initiated by the command sequence: FEX <return>, BGX <return> (where X could be any axis on the controller, X,Y,Z, or W). The Find Edge routine will cause the motor to accelerate, then slew at constant speed until a transition is detected in the logic state of the Home input. The direction of the FE motion is dependent on the state of the home switch. Refer to the CN command to set the correspondence between the Home Input voltage and motion direction. The motor will decelerate to a stop when a transition is seen on the input. The acceleration rate, deceleration rate and slew speed are specified by the user, prior to the movement, using the commands AC, DC, and SP. *It is recommended that a high deceleration value be used so the motor will decelerate rapidly after sensing the Home switch.*

The Find Index routine is initiated by the command sequence: FIX <return>, BGX <return> (where X could be any axis on the controller, X,Y,Z, or W). Find Index will cause the motor to accelerate to the user-defined slew speed (SP) at a rate specified by the user with the AC command and slew until the controller senses a change in the index pulse signal from low to high. The motor then decelerates to a stop at the rate previously specified by the user with the DC command. *Although Find Index is an option for homing, it is not dependent upon a transition in the logic state of the Home input, but instead is dependent upon a transition in the level of the index pulse signal.*

The Standard Homing routine is initiated by the sequence of commands HMX <return>, BGX <return> (where X could be any axis on the controller, X,Y,Z, or W). Standard Homing is a combination of Find Edge and Find Index homing. Initiating the standard homing routine will cause the motor to slew until a transition is detected in the logic state of the Home input. The motor will accelerate at the rate specified by the command, AC, up to the slew speed. After detecting the transition in the logic state on the Home Input, the motor will decelerate to a stop at the rate specified by the command DC. After the motor has decelerated to a stop, it switches direction and approaches the transition point at the speed of 256 counts/sec. When the logic state changes again, the motor moves forward (in the direction of increasing encoder count) at the same speed, until the controller senses the index pulse. After detection, it decelerates to a stop and defines this position as 0. The logic state of the Home input can be interrogated with the command MG _HMX. This command returns a 0 or 1 if the logic state is low or high (dependent on the CN command). The state of the Home input can also be interrogated indirectly with the TS command.

For examples and further information about Homing, see command HM, FI, FE of the Command Reference and the section entitled 'Homing' in the Programming Motion Chapter of this manual.

Abort Input

The function of the Abort input is to immediately stop the controller upon transition of the logic state.

NOTE: The response of the abort input is significantly different from the response of an activated limit switch. When the abort input is activated, the controller stops generating motion commands immediately, whereas the limit switch response causes the controller to make a decelerated stop.

NOTE: The effect of an Abort input is dependent on the state of the off-on-error function (OE) for each axis. If the Off-On-Error function is enabled for any given axis, the motor for that axis will be turned off when the abort signal is generated. This could cause the motor to 'coast' to a stop since it is no longer under servo control. If the Off-On-Error function is disabled, the motor will decelerate to a stop as fast as mechanically possible and the motor will remain in a servo state.

All motion programs that are currently running are terminated when a transition in the Abort input is detected. For information on setting the Off-On-Error function, see the Command Reference, OE.

Uncommitted Digital Inputs

The general use inputs are TTL and are accessible through the ICM-2900 as XLATCH-WLATCH (inputs 1-4) and IN5-IN8. These inputs can be interrogated with the use of the command TI (Tell Inputs), the operand _TI, and the function @IN[n] (see Chapter 7, Mathematical Functions and Expressions).

Amplifier Interface

The DMC-18x2 analog command voltage, ACMD, ranges between +/-10V. This signal, along with GND, provides the input to the power amplifiers. The power amplifiers must be sized to drive the motors and load. For best performance, the amplifiers should be configured for a current mode of operation with no additional compensation. The gain should be set such that a 10 Volt input results in the maximum required current. If the controller is operating in stepper mode, the pulse and direction signals will be input into a stepper drive.

The DMC-18x2 also provides an amplifier enable signal, AEN. This signal is deactivated under the following conditions: the watchdog timer activates, the motor-off command, MO, is given, or the OE1command (Enable Off-On-Error) is given and the position error exceeds the error limit. As shown in Figure 3-1, AEN can be used to disable the amplifier for these conditions.

The standard configuration of the AEN signal is TTL active high. In this configuration the AEN signal will be high when the controller expects the amplifier to be enabled. The polarity and the amplitude can be changed if you are using the ICM-2900 interface board. To change the polarity from active high (5 volts= enable, zero volts = disable) to active low (zero volts = enable, 5 volts= disable), replace the 7407 IC with a 7406. Note that many amplifiers designate the enable input as 'inhibit'.

To change the voltage level of the AEN signal, note the state of the resistor pack on the ICM/AMP-1900 or ICM-2900. When Pin 1 is on the 5V mark, the output voltage is 0-5V. To change to 12 volts, pull the resistor pack and rotate it so that Pin 1 is on the 12 volt side. If you remove the resistor pack, the output signal is an open collector, allowing the user to connect an external supply with voltages up to 24V.

To connect an external 24V supply, remove the resistor pack, RP1, from the interconnect board. Connect a 2.2kΩ resistor in series between the +24V of the supply and the amplifier enable terminal on the interconnect (AMPEN). Then wire the AMPEN to the enable pin on the amplifier. Connect the -24V to the ground, GND, of the interconnect and connect the GND of the interconnect to the GND of the amplifier. **NOTE:** Before connecting the GND of the interconnect, to the GND of the amplifier, check for continuity between the two points. If continuity exists, do not connect the two points. If continuity does not exist, then you must connect the points to create a reference for the motor command signal.

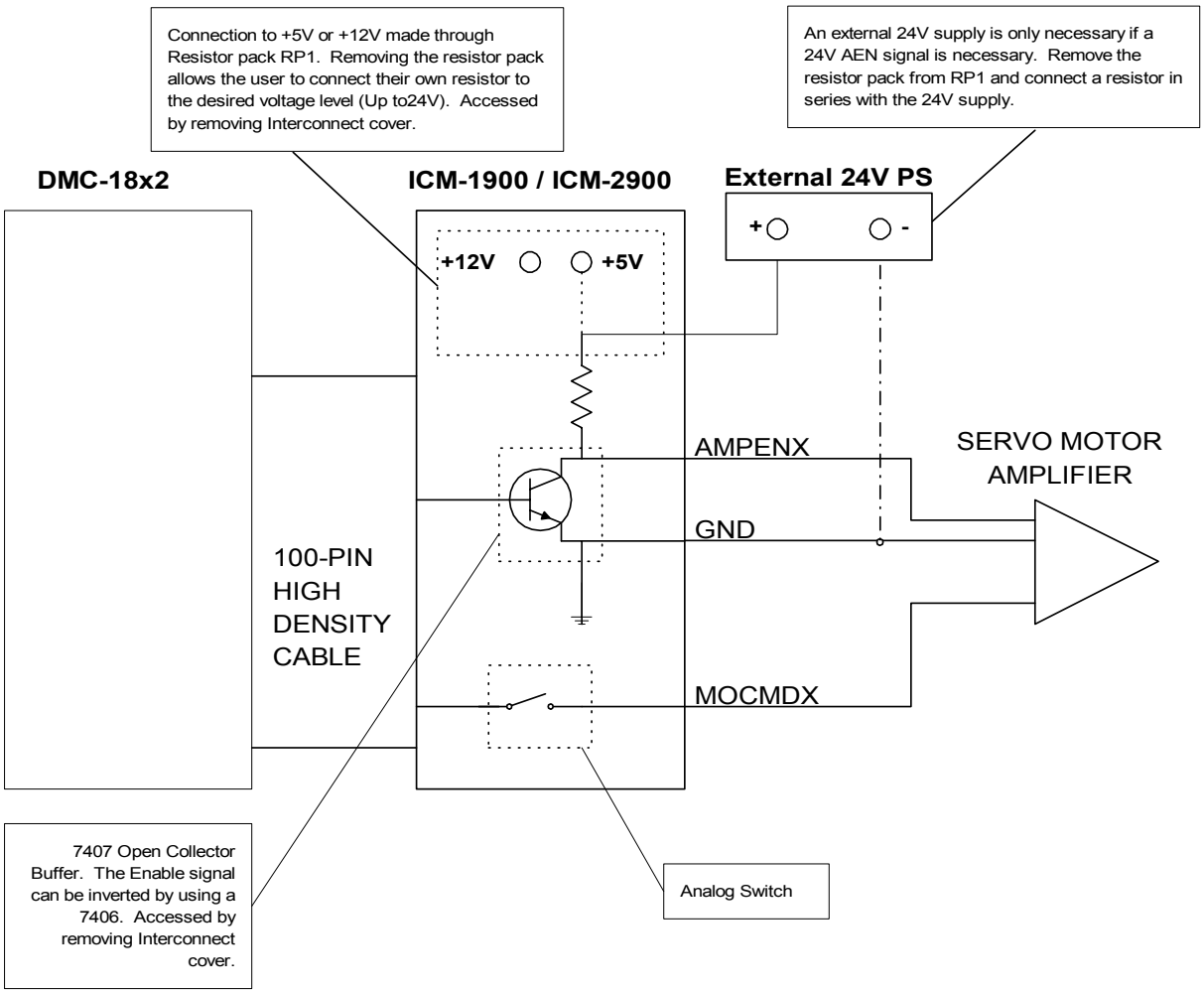
Connection to +5V or +12V made through Resistor pack RP1. Removing the resistor pack allows the user to connect their own resistor to the desired voltage level (Up to24V). Accessed by removing Interconnect cover.
An external 24V supply is only necessary if a 24V AEN signal is necessary. Remove the resistor pack from RP1 and connect a resistor in series with the 24V supply.
DMC-18x2
ICM-1900 / ICM-2900
External 24V PS
+
-
+12V
+5V
AMPENX
SERVO MOTOR AMPLIFIER
GND
100-PIN HIGH DENSITY CABLE
MOCMDX
7407 Open Collector Buffer. The Enable signal can be inverted by using a 7406. Accessed by removing Interconnect cover.
Analog Switch

Figure 3-1 - Connecting AEN to the motor amplifier

TTL Inputs

As previously mentioned, the DMC-18x2 has 8 uncommitted TTL level inputs. The command @IN, or TI will read the state of the inputs. For more information on these commands refer to the Command Reference.

The reset input is also a TTL level, non-isolated signal and is used to locally reset the DMC-18x2 without resetting the PC.

TTL Outputs

The DMC-18x2 provides eight general use outputs, an output compare and an error signal output.

The general use outputs are TTL and are accessible through the ICM-2900 as OUT1 thru OUT8. These outputs can be turned On and Off with the commands, SB (Set Bit), CB (Clear Bit), OB (Output Bit), and OP (Output Port). The outputs can sink or source up to 24 mA. For more information about these commands, see the Command Reference. The value of the outputs can be checked with the operand _OP and the function @OUT[] (see Chapter 7, Mathematical Functions and Expressions).

NOTE: For systems using the ICM-2900 interconnect module, the ICM-2900 has an option to provide optoisolation on the outputs. In this case, the user provides an isolated power supply (+5 volts to +24 volts and ground). For more information, consult Galil.

The output compare signal is TTL and is available on the ICM-2900 as CMP. Output compare is controlled by the position of any of the main encoders on the controller. The output can be programmed to produce an active low pulse (1usec) based on an incremental encoder value or to activate once when an axis position has been passed. For further information, see the command OC in the Command Reference.

The error signal output is available on the interconnect module as ERROR. This is a TTL signal which is low when the controller has an error.

Note: When the error signal is low, the LED on the controller will be on, indicating one of the following error conditions:

1. At least one axis has a position error greater than the error limit. The error limit is set by using the command ER.
2. The reset line on the controller is held low or is being affected by noise.
3. There is a failure on the controller and the processor is resetting itself.
4. There is a failure with the output IC which drives the error signal.

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Chapter 4 - Software Tools and Communications

Introduction

Galil software is available for PC computers running Microsoft Windows® to communicate with the DMC-18x2 controller via the PCI bus. Standard Galil communications software utilities are available for Windows operating systems, which includes **SmartTERM** and **WSDK**. These software packages are developed to operate under Windows 98SE, ME, NT4.0, 2000, and XP, and include all the necessary drivers to communicate with the PCI card. In addition, Galil offers software development tools (**CToolkit** and **ActiveX Toolkit)** to allow users to create their own application interfaces using programming environments such as C, C++, Visual Basic, and LabVIEW.

Galil also offers some basic software drivers and utilities for non-Windows environments such as DOS, Linux, and QNX. For users who prefer to develop there own drivers, details are provided in this chapter describing the PCI communication registers used on the DMC-18x2 controller.

The following sections in this chapter are a brief introduction to the software tools and communication techniques used by Galil. Figure-1 illustrates the software hierarchy that Galil communications software employs. At the application level, SmartTERM and WSDK are the basic programs that the majority of users will need to communicate with the controller, to perform basic setup, and to develop application code (.DMC programs) that is downloaded to the controller. At the Galil API level, Galil provides software tools (ActiveX and API functions) for advanced users, who wish to develop their own custom application programs to communicate with the controller. Custom application programs can utilize API function calls directly to our DLL's, or use our ActiveX COM objects, which simplifies programming. At the driver level, we provide fundamental hardware interface information for users who desire to create their own drivers.

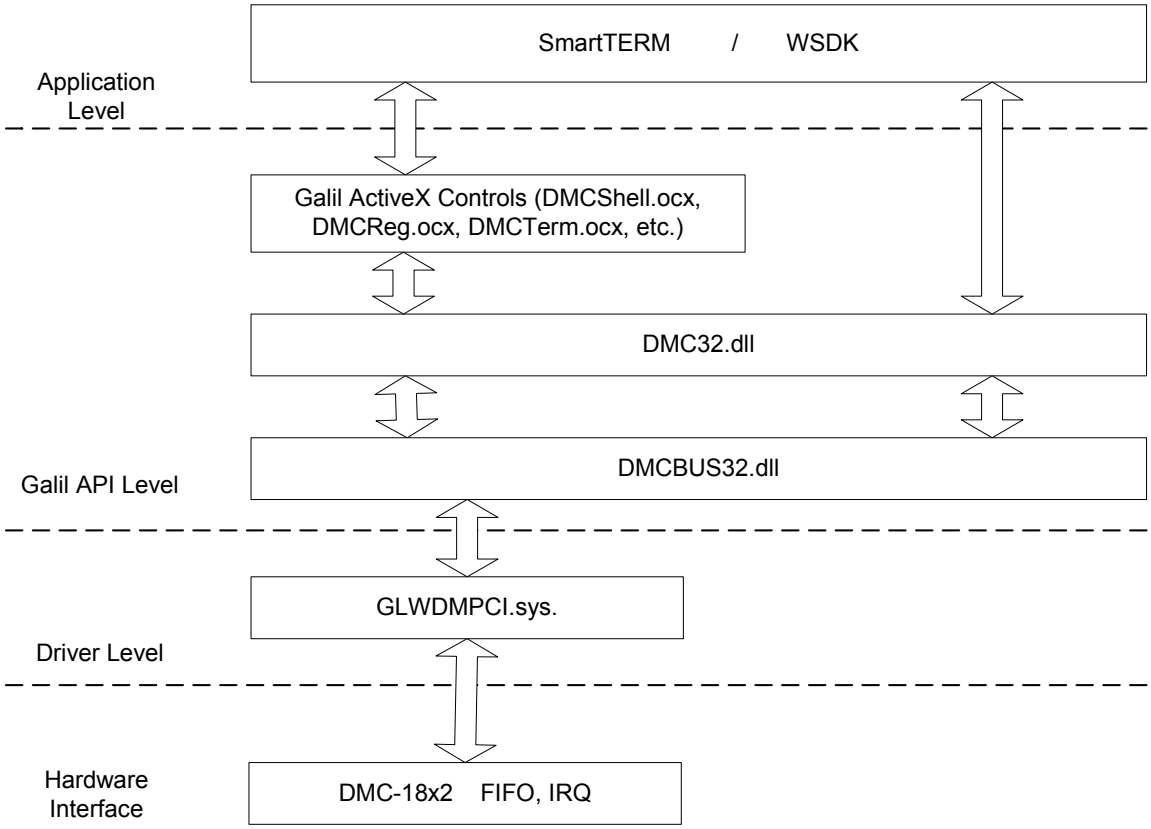

Figure 4.1 - Software Communications Hierarchy

Galil SmartTERM

SmartTERM is Galil's basic communications utility that allows the user to perform basic tasks such as sending commands directly to the controller, editing, downloading, and executing DMC programs, uploading and downloading arrays, and updating controller firmware. The latest version of SmartTERM can be downloaded from the Galil website at http://www.galilmc.com/support/download.html

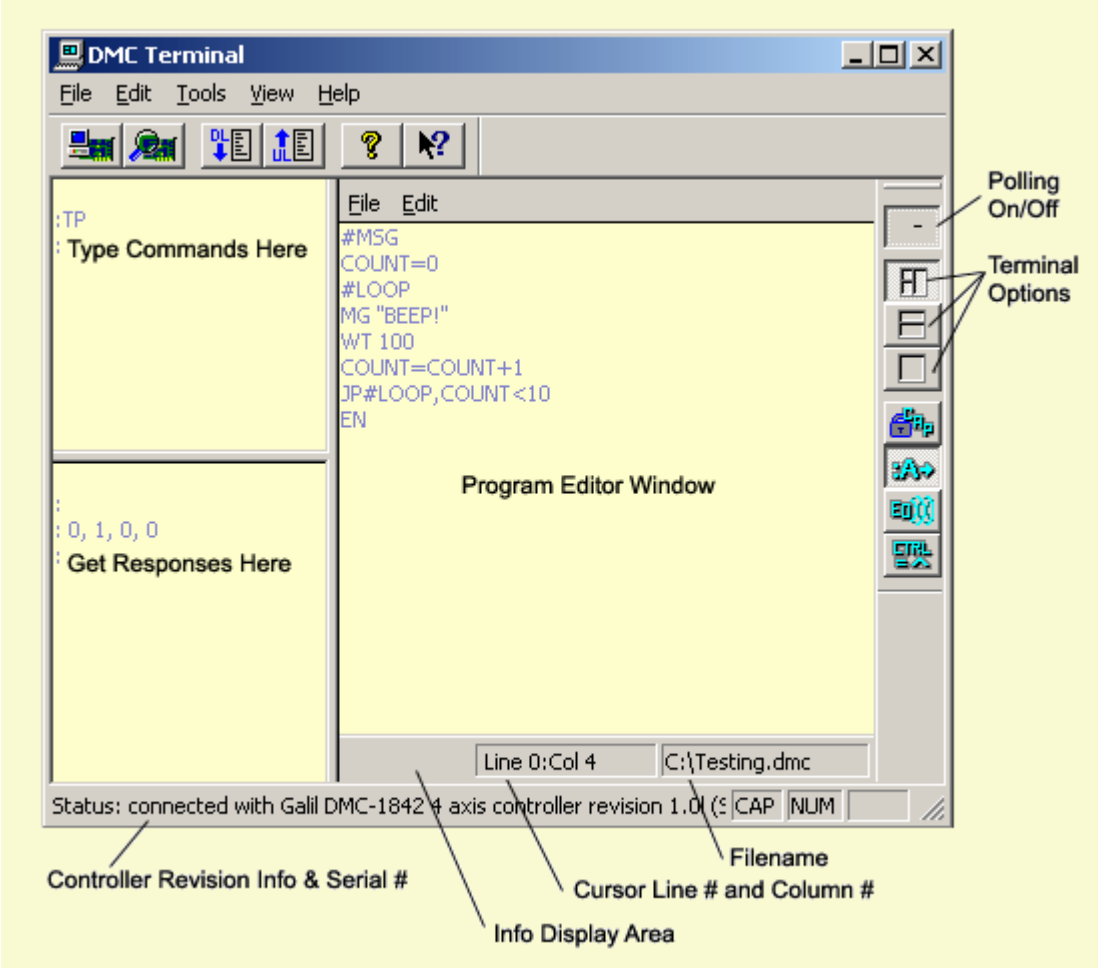

Figure 4.2 - Galil SmartTERM layout

The following SmartTERM **File** menu items briefly describe some basic features of the application.

Download File... — Launches a file-open dialog box that selects a file (usually a DMC file) to be downloaded to the controller. This command uses the DL command to download the file, clearing all programs in the controller's RAM.

Upload File... — Opens a file save-as dialog that creates a file for saving the DMC program

	that is in the controller's RAM. This command uses the UL command to upload the file.
Send File...	Launches a file-open dialog box that selects a file (usually a DMC file) to be sent to the controller. Each line of the file is sent to the controller as a command and is executed immediately.
Download Array...	Opens the "Download Array" dialog box that allows an array in the controller's RAM to be defined and populated with data. The dialog box uses the DMC32.dll 's DMCArrayDownload function to download the array. The controller's firmware must be recent enough to support the QD command. Array values specified in the data file must be comma separated or CRLF deliminated.
Upload Array...	Opens the "Upload Array" dialog box that allows an array in the controller's RAM to be saved to a file on the hard disk. The dialog box uses the DMC32.dll 's DMCArrayUpload function to upload the array. The controller's firmware must be recent enough to support the QU command.
Convert File ASCII to Binary...	Opens a dialog box that allows a file containing Galil ASCII language commands to be converted to Galil binary commands and saves the result to the specified file name.
Convert File Binary to ASCII...	Opens a dialog box that allows a file containing Galil binary language commands to be converted to Galil ASCII commands and saves the result to the specified file name.
Send Binary File...	Launches a file-open dialog box that selects a file (usually a DMC file) to be sent to the controller. This file can contain binary commands. Each line of the file is sent to the controller as a command and executed immediately.

Additionally, the **Tools** menu items described below provide some advanced tasks such as updating firmware, diagnostics, accessing the registry editor, and resetting the controller.

Select Controller...	Opens the "Select Controller" dialog box that displays the currently registered Galil Motion Controllers. Selecting a controller from the list and clicking on the OK button or double-clicking a controller will cause the application to close any current connections to a controller and open a new connection to the selected controller. DMCTerminal only connects to a single controller at a time. However, multiple instances of the application can be open at once.
Disconnect from Controller	Causes the currently open connection to a Galil Motion Controller to be closed.
Controller Registration...	Opens the "Edit Registry" dialog box, which allows the Galil Registry entries to be edited or new entries for non bus-based controllers to be created or deleted.
DMC Program Editor...	Causes the terminal to enter "Smart Terminal with Editor" mode. This is the same as clicking on the "Smart Terminal with Editor" mode button on the terminal window's toolbar.
Reset Controller	Offers three "reset" options. "Reset Controller" sends an RS command to the controller. The RS command does not clear any saved variables, programs, or parameters. "Master Reset" performs a master reset on the controller. A Master Reset does clear any saved variables, programs, or parameters. "Clear Controller's FIFO" causes the controller's output FIFO to be cleared of data.
Device Driver	The Device Driver menu selection is available to operating systems and/or controllers that have device drivers that can be stopped and started. This includes drivers on NT4.0 and serial and Ethernet controllers on all operating systems.
Diagnostics	The "Diagnostics" menu allows diagnostics to be stopped and started. It also will load the diagnostics output file specified in the Tools/Options menu to be loaded into the editor window for analysis. The "Test Controller" command tests the current controller with a series of standard communication tests.

Update Firmware...	The "Update Firmware" command allows new firmware to be downloaded to the currently connected controller. Selecting this command will cause a file-open dialog box to open, allowing the user to specify a *.HEX file to be specified for download. The latest firmware files can be downloaded from Galil's website.
Display Data Record	Causes the Data Record dialog box to be displayed for the currently connected controller. The dialog automatically configures itself to display the data record for each type of Galil Motion Controller.
Options	The Options menu command causes the Options dialog to be displayed. The Options dialog box allows several application options to be set. These option settings are preserved between uses.

DMC Program Editor Window

The Program Editor Window is used to create application programs (.DMC) that are downloaded to the controller. The editor window is also useful for uploading and editing programs already residing in the controller memory. This window has basic text editing features such as copy, cut, paste, etc. Also the editor window File function allows an application program to be downloaded with compression (80 characters wide) This allows the user to write an application program in the editor window that is longer than the normal line limitation (1000 lines) and download it to the controller.

Additionally, dynamic syntax help is available by activating the syntax help button ("**:A->**" icon**)**.

DMC Data Record Display

The DMC SmartTERM utility program includes a "Data Record" display window that is useful for observing the current status of all the major functions of the controller including axis specific data, I/O status, application program status, and general status.

When using a DMC-18x2 controller the data record data is provided through the main FIFO.

To display the Data Record (shown in Fig 4.3), select **Display Data Record** under the **Tools** menu of DMC SmartTERM.

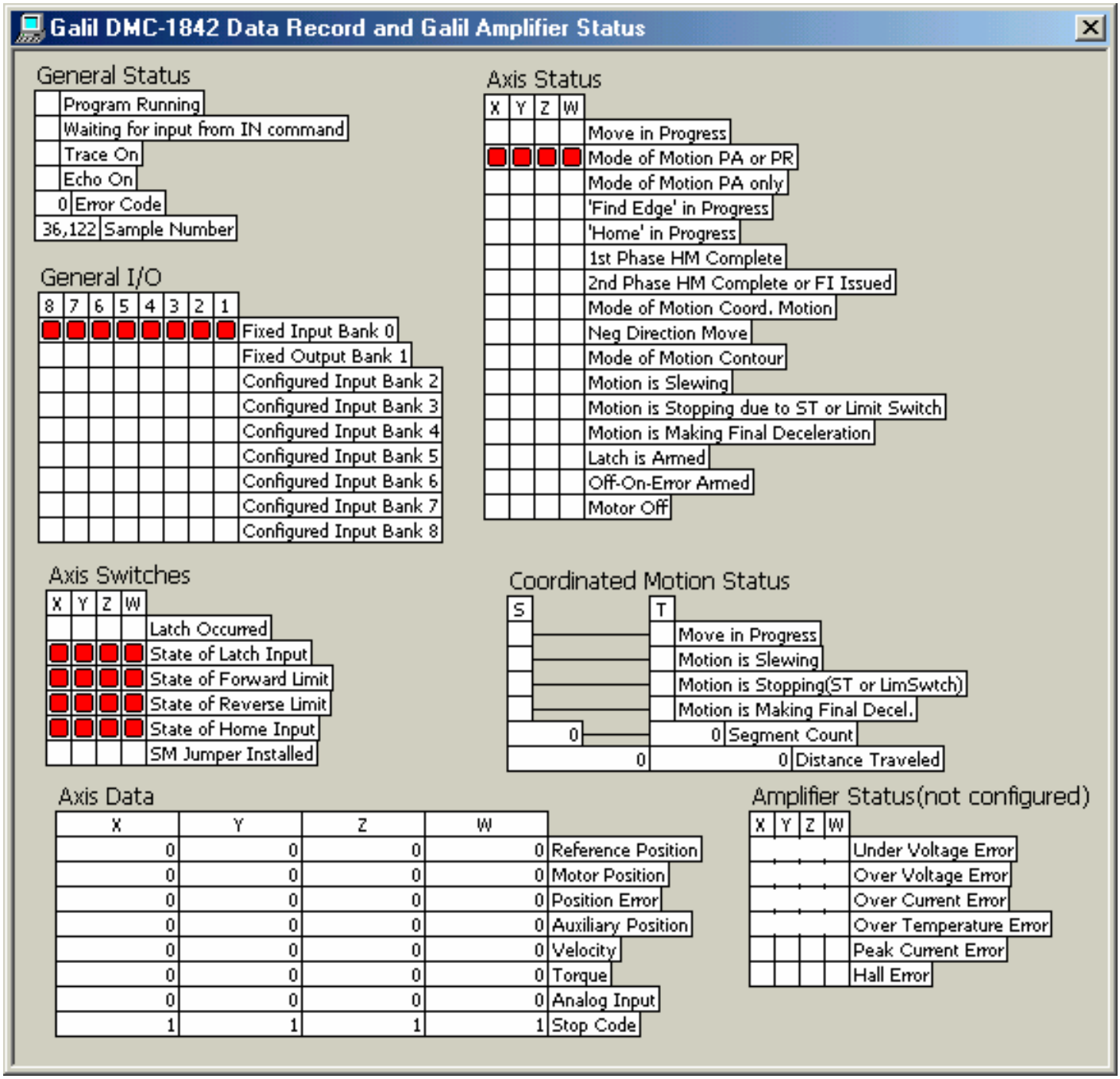

Figure 4.3 - Data Record Display for a DMC-1842

The Data Record display is user customizable so that all, or just parts, of the record can be displayed. To modify the display, right click on an object to access the options. For detailed information about the features of the Galil DMC SmartTERM including the Data Record, please consult **Help Topics** under the **Help** menu.

Communication Settings for ISA and PCI

The Galil SmartTERM application installation (as well as WSDK, ActiveX, and DMCWIN32 installations) includes the necessary drivers and .DLL files required to communicate with the Galil controller. The drivers are automatically installed and default communications settings are applied to the device by the driver when a card is installed as per the installation procedure outlined in Ch.2. However, some advanced settings are available to modify the communications methods and data record access. These settings are accessed through the Galil Registry Editor after the card is properly installed.

Galil Registry Editor

The "Edit Registry" dialog box (shown in Fig 4.4) can be accessed by selecting **Controller Registration…** under the **Tools** menu (or by selecting the toolbar icon with the magnifying glass) within DMC SmartTERM. The Edit Registry dialog shows the current controller models installed to the PC along with their associated I/O addresses, interrupt lines, and controller serial numbers. The Galil Registry is part of the DMCReg.ocx ActiveX object (refer to Fig 4.1). This ActiveX control is used to create, maintain, and modify the critical communication parameters, which are discussed next.

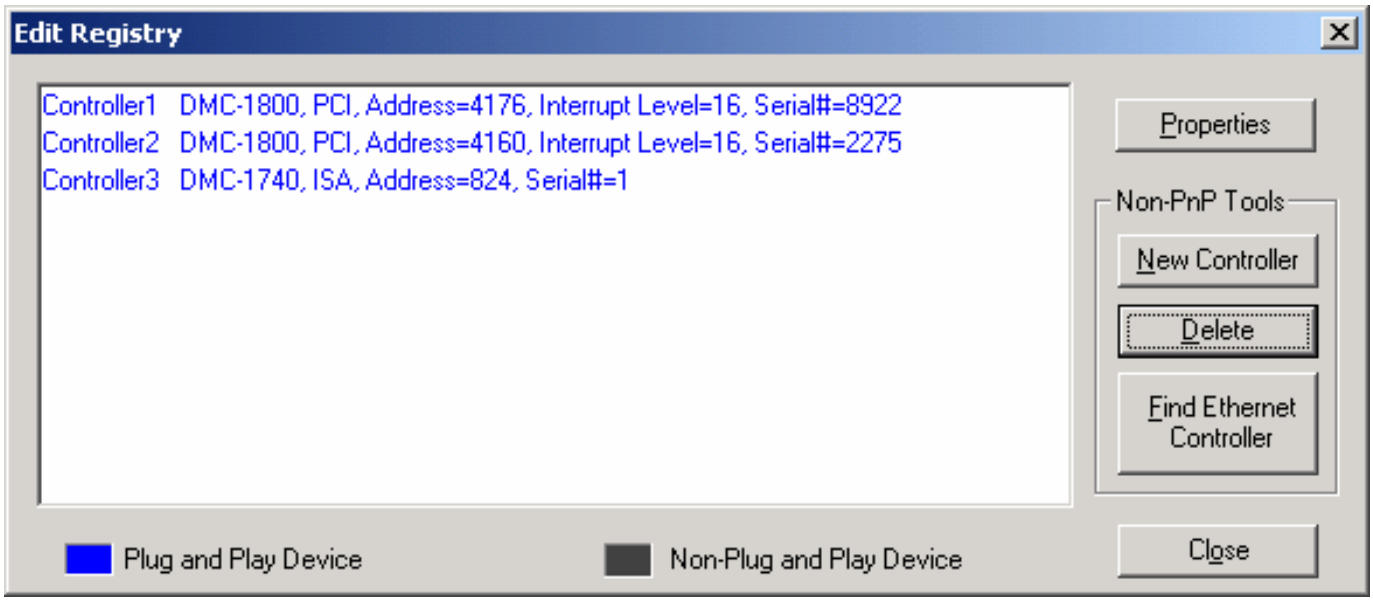

Figure 4.4 - Galil Registry Editor

Setting Communications Parameters and Methods

To access the Controller Communication Parameters dialog, highlight the desired controller in the Galil Registry Editor accessed through SmartTERM and select the **Properties** command button.

The timeout property under the **General Parameters** tab (shown in Fig 4.5) allows the user to select the timeout period that the Galil software waits for a response from the controller before generating an error. If the controller does not reply with the data response and a colon (or just a colon for commands that do not invoke responses), then the Galil software API will generate the timeout error code -1 (A

time-out occurred while waiting for a response from the Galil controller). The default setting for the timeout is 5000ms, which should be sufficient for most cases.

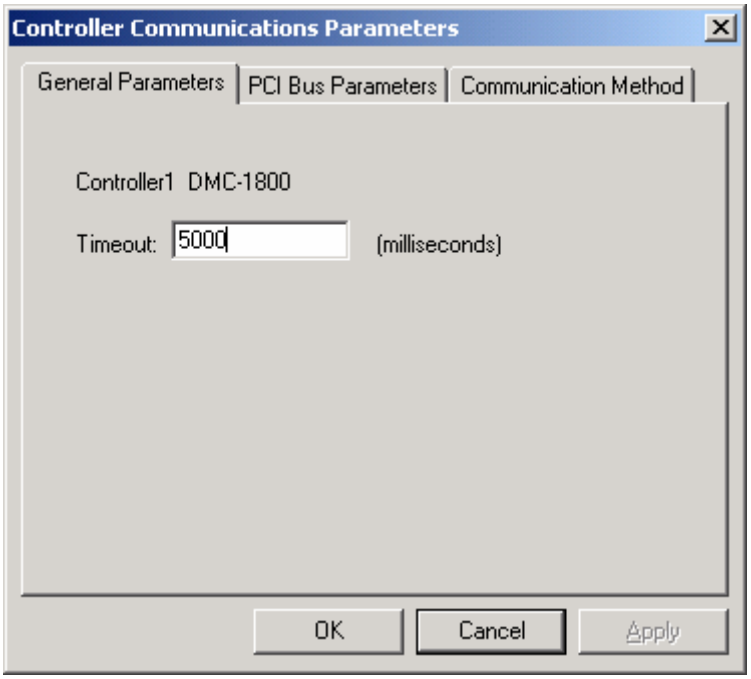

Figure 4.5 - General Communications Parameters Dialog

Advanced communications settings are available under the **Communication Method** tab to allow different methods of communications to be utilized (shown in Fig 4.6). The version 7 (and higher) drivers and .DLL's allow for three different methods of communications: Interrupt, Stall, and Delay.

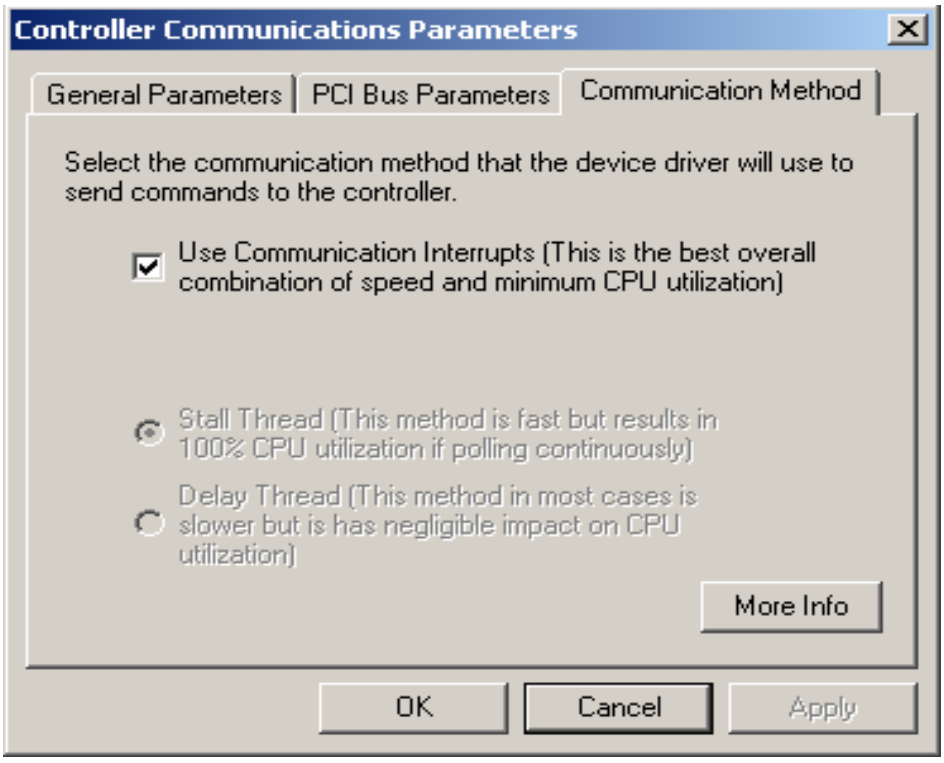
Controller Communications Parameters
General Parameters
PCI Bus Parameters
Communication Method
Select the communication method that the device driver will use to send commands to the controller.
Use Communication Interrupts (This is the best overall combination of speed and minimum CPU utilization)
Stall Thread (This method is fast but results in 100% CPU utilization if polling continuously)
Delay Thread (This method in most cases is slower but is has negligible impact on CPU utilization)
More Info
OK
Cancel
Apply

Figure 4.6 - Controller Communications Method Dialog Box

Interrupt Communications Method

The interrupt method overall is the most efficient of the three methods. The software communications method uses a hardware interrupt to notify the application that a response or unsolicited data is available. This allows for greater efficiency and response time, since the drivers do not have to “poll” the buffers for the data. Additionally, the interrupt method allows for data record caching.

The interrupt method uses bus level interrupts (IRQ) from the controller to notify the PC that data is available. This requires that the Controller be configured with a valid interrupt line. For DMC-18x2 controllers the interrupt is configured automatically. Firmware version 2.0m (and greater) is required for the “communications interrupt” method to be available. For complete information on the different communications methods, select the **More Info** button on the Communications parameters dialog box.

Stall Thread and Delay Thread Methods

Users can also choose between "Delay" and "Stall" methods. These two methods are available for the DMC-18x2 controller and affect how the software "waits" for a response from the controller when a command is sent. If a controller is configured with the "Delay" method, the thread waiting for a command response gives up its time slice, allowing other processes running on the operating system to proceed. This method can slow communication, but results in negligible CPU utilization. The second method, the "Stall" method, uses the opposite strategy. The thread that performs I/O with the controller maintains ownership of the CPU and polls the controller until a response is received. This approach is essentially the same method employed in previous versions (< V7) of the Galil communication DLLs and drivers. While the "Stall" method does not have to wait for its thread to become eligible for execution, it does result in 100% CPU utilization while communicating with the controller.

Windows Servo Design Kit (WSDK)

The Galil Windows Servo Design Kit includes advanced tuning and diagnostic tools that allows the user to maximize the performance of their systems, as well as aid in setup and configuration of Galil controllers. WSDK is recommended for all first time users of Galil controllers. WSDK has an automatic servo tuning function that adjusts the PID filter parameters for optimum performance and displays the resulting system step response. A four-channel storage scope provides a real-time display of the actual position, velocity, error and torque. WSDK also includes impulse, step and frequency response tests, which are useful for analyzing system stability, bandwidth and resonances. WSDK can be purchased from Galil via the web at http://store.yahoo.com/galilmc/wsdk32.html.

Features Include:

- Automatic tuning for optimizing controller PID filter parameters
- Provides impulse, step and frequency response tests of actual hardware
- Four-channel storage scope for displaying real-time position, velocity, error and torque
- Displays X versus Y position for viewing actual 2-D motion path
- Terminal editor and program editor for easy communication with the controller

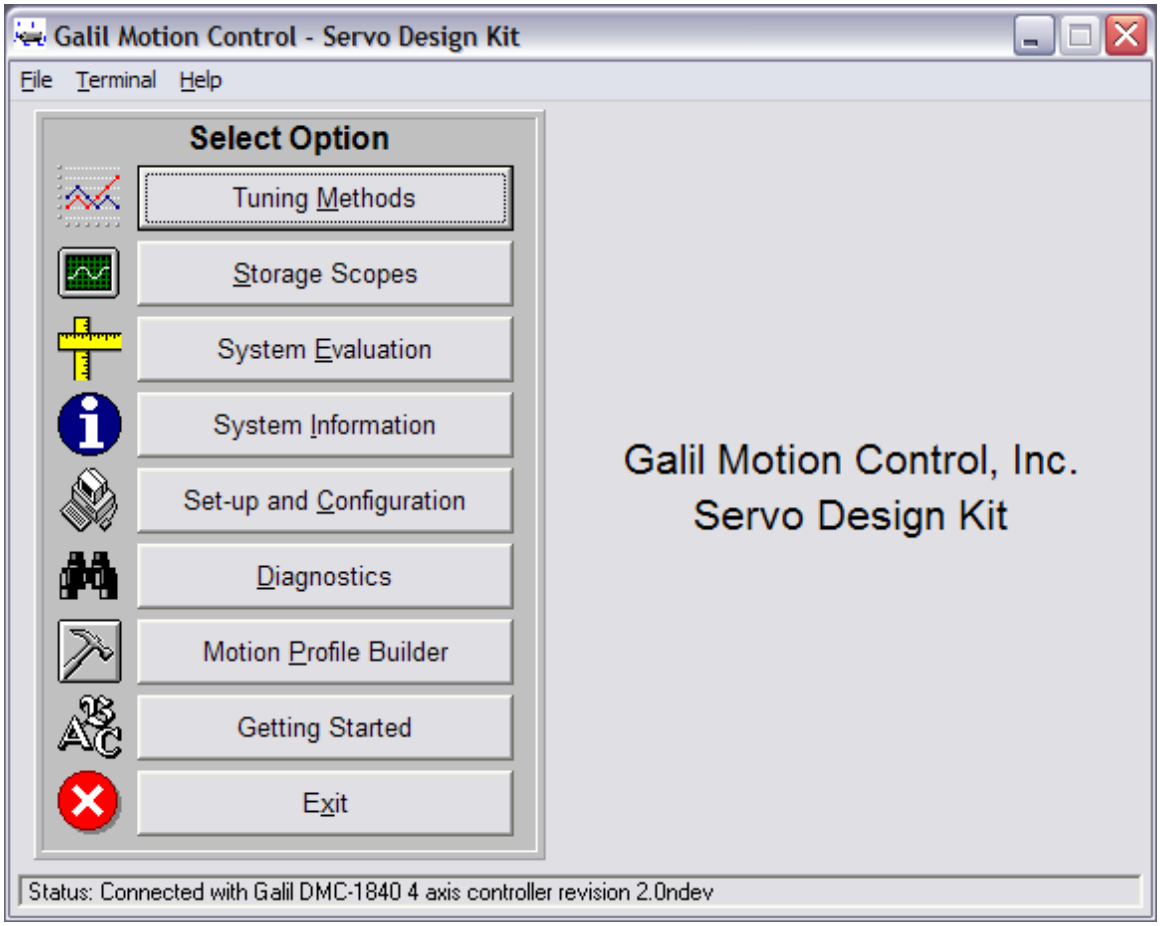

Figure 4.7- WSDK Main Screen

Creating Custom Software Interfaces

Galil provides programming tools so that users can develop their own custom software interfaces to a Galil controller. These tools include the **ActiveX Toolkit** and **DMCWin.**

ActiveX Toolkit

Galil's ActiveX Toolkit is useful for the programmer who wants to easily create a custom operator interface to a Galil controller. The ActiveX Toolkit includes a collection of ready-made ActiveX COM controls for use with Visual Basic, Visual C++, Delphi, LabVIEW and other ActiveX compatible programming tools. The most common environment is Visual Basic 6, but Visual Basic.NET, Visual C++, Wonderware, LabVIEW and HPVEE have all been tested by Galil to work with the .OCX controls. The ActiveX Toolkit can be purchased from Galil at http://store.yahoo.com/galilmc/actoolsoffor.html

The ActiveX toolkit can save many hours of programming time. Built-in dialog boxes are provided for

quick parameter setup, selection of color, size, location and text. The toolkit controls are easy to use and provide context sensitive help, making it ideal for even the novice programmer.

ActiveX Toolkit Includes:

- a terminal control for sending commands and editing programs
- a polling window for displaying responses from the controller such as position and speed
- a storage scope control for plotting real time trajectories such as position versus time or X versus Y
- a send file control for sending contour data or vector DMC files
- a continuous array capture control for data collection, and for teach and playback
- a graphical display control for monitoring a 2-D motion path
- a diagnostics control for capturing current configurations
- a display control for input and output status
- a vector motion control for tool offsets and corner speed control

For more detailed information on the ActiveX Toolkit, please refer to the user manual at http://www.galilmc.com/support/manuals/activex.pdf.

DMCWin Programmers Toolkit

DMCWin is a programmer's toolkit for C/C++ and Visual Basic users. The toolkit includes header files for the Galil communications API, as well as source code and examples for developing Windows® programs that communicate to Galil Controllers. The Galil communications API includes functions to send commands, download programs, download/upload arrays, access the data record, etc. For a complete list of all the functions, refer to the DMCWin user manual at http://www.galilmc.com/support/manuals/dmcwin.pdf.

This software package is free for download and is available at http://www.galilmc.com/support/download.html.

Galil Communications API with C/C++

When programming in C/C++, the communications API can be used as included functions or through a class library. All Galil communications programs written in C must include the DMCCOM.H file and access the API functions through the declared routine calls. C++ programs can use the DMCCOM.H routines or use the class library defined in DMCWIN.H.

After installing DMCWin into the default directory, the DMCCOM.H header file is located in C:\Program Files\Galil\DMCWIN\INCLUDE. C++ programs that use the class library need the files DMCWIN.H and DMCWIN.CPP, which contain the class definitions and implementations respectively. These can be found in the C:\ProgramFiles\Galil\DMCWIN\CPP directory.

To link the application with the DLL's, the DMC32.lib file must be included in the project and is located at C:\Program Files\Galil\DMCWIN\LIB

Example: A simple console application that sends commands to the controller

To initiate communication, declare a variable of type HANDLEDMC (a long integer) and pass the address of that variable in the DMCOpen() function. If the

DMCOpen() function is successful, the variable will contain the handle to the Galil controller, which is required for all subsequent function calls. The following simple example program written as a Visual C console application tells the controller to move the X axis 1000 encoder counts. Remember to add DMC32.LIB to your project prior to compiling.

```
#include <windows.h>
#include <dmccom.h>
long rc;
HANDLEDMC hDmc;
HWND hWnd;
int main(void)
{
      // Connect to controller number 1
      rc = DMCOpen(1, hWnd, &hDmc);
      if (rc == DMCNOERROR)
      {
      char szBuffer[64];
      // Move the X axis 1000 counts
      rc = DMCCommand(hDmc, "PR1000;BGX;", szBuffer,
     sizeof(szBuffer));
     // Disconnect from controller number 1 as the last action
      rc = DMCClose(hDmc);
      }
     return 0;
}
```

Galil Communications API with Visual Basic

Declare Functions

To use the Galil communications API functions, add the module file included in the C:\ProgramFiles\Galil\DMCWIN\VB directory named DMCCOM40.BAS. This module declares the routines making them available for the VB project. To add this file, select **'Add Module'** from the **'Project'** menu in VB5/6.

Sending Commands in VB

Most commands are sent to the controller with the DMCCommand() function. This function allows any Galil command to be sent from VB to the controller. The DMCCommand() function will return the response from the controller as a string. Before sending any commands the DMCCOpen() function must be called. This function establishes communication with the controller and is called only once.

This example code illustrates the use of DMCOpen() and DMCCommand(). A connection is made to controller #1 in the Galil registry upon launching the application. Then, the controller is sent the command 'TPX' whenever a command button is pressed. The response is then placed in a text box. When the application is closed, the controller is disconnected.

To use this example, start a new Visual Basic project, place a Text Box and a Command Button on a Form, add the DMCCOM40.BAS module, and type the following code:

```
Dim m_nController As Integer
Dim m_hDmc As Long
Dim m_nRetCode As Long
```

```
Dim m_nResponseLength As Long
Dim m_sResponse As String * 256

Private Sub Command1_Click()
    m_nRetCode = DMCCommand(m_hDmc, "TPX", m_sResponse, m_nResponseLength)
    Text1.Text = Val(m_sResponse)
End Sub

Private Sub Form_Load()
    m_nResponseLength = 256
    m_nController = 1
    m_nRetCode = DMCOpen(m_nController, 0, m_hDmc)
End Sub

Private Sub Form_Unload(Cancel As Integer)
    m_nRetCode = DMCClose(m_hDmc)
End Sub
```

Where:

'm_nController' is the number for the controller in the Galil registry.

'm_hDmc' is the DMC handle used to identify the controller. It is returned by DMCOpen.

'm_nRetCode' is the return code for the routine.

'm_nResponseLength' is the response string length which must be set to the size of the response string.

'm_sResponse' is the string containing the controller response to the command.

DOS, Linux, and QNX tools

Galil offers unsupported code examples that demonstrate communications to the controller using the following operating systems.

DOS

DOS based utilities & Programming Libraries for Galil controllers, which includes a terminal, utilities to upload and download programs, and source code for BASIC and C programs. Download DMCDOS at http://www.galilmc.com/support/download.html#dos.

Linux

Galil has developed code examples for the Linux operating system. The installation includes sample drivers to establish communication with Galil PCI and ISA controllers. The current version of the software has been tested under Redhat 6.X O.S. All source codes for the drivers and other utilities developed for Linux are available to customers upon request. Linux drivers are available for ISA and PCI cards under Kernel 2.2. Drivers are also available for the PCI card only for Kernel 2.4.

For more information on downloading and installing the Linux drivers for Galil controllers, download the Linux manual at: http://www.galilmc.com/support/manuals/lnxmanual.pdf.

QNX

Galil offers sample drivers for ISA and PCI cards for the QNX 4.24 operating system. We also offer drivers and utilities for QNX 6.2 for PCI only. Download at http://www.galilmc.com/support/download.html#linux.

Command Format and Controller Response

Instructions to the DMC-18x2 may be sent in Binary or ASCII format. Binary communication allows for faster data processing since the controller does not have to first decode the ASCII characters.

ASCII Command mode

In the ASCII mode, instructions are represented by two characters followed by the appropriate parameters. Each instruction must be terminated by a carriage return or semicolon.

The DMC-18x2 decodes each ASCII character (one byte) one at a time. It takes approximately .350 msec for the controller to decode each command and execute it.

After the instruction is decoded, the DMC-18x2 returns a colon (:) if the instruction was valid or a question mark (?) if the instruction was not valid.

For instructions that return data, such as Tell Position (TP), the DMC-18x2 will return the data followed by a carriage return, line feed, and colon (:).

An echo function is also provided to enable associating the DMC-18x2 response with the command sent. The echo is enabled by sending the command EO 1 to the controller.

Binary Command Mode

Some commands have an equivalent binary value for the controllers. These values are listed in the Command Reference next to the command in parentheses in hexadecimal format . Binary communication mode can be executed much faster than ASCII commands since the controller does not have to first decode the ASCII characters. Binary format can only be used when commands are sent from the PC and cannot be embedded in an application program.

Binary Command Format

All binary commands have a 4 byte header followed by data fields. The 4 bytes are specified in hexadecimal format.

Binary Header Format:

Byte 1 specifies the hexadecimal command number between 80 to FF.

Byte 2 specifies the # of bytes in each field as 0, 1, 2, 4 or 6 as follows:

00	No datafields (i.e. SH or BG)
01	One byte per field
02	One word (2 bytes per field)
04	One long word (4 bytes) per field
06	Galil real format (4 bytes integer and 2 bytes fraction)

Byte 3 specifies whether the command applies to coordinated motion on the "S" or "T" axis as follows:

Bit 1 = T axis coordinated motion movement
Bit 0 = S axis coordinated motion movement

For example, the command STS commands motion to stop on the S axis vector motion. The third byte for the equivalent binary command would then be 01.

Byte 4 specifies the axis # or data field as follows

Bit 7 = H axis or 8th data field
Bit 6 = G axis or 7th data field
Bit 5 = F axis or 6th data field
Bit 4 = E axis or 5th data field
Bit 3 = D axis or 4th data field
Bit 2 = C axis or 3rd data field
Bit 1 = B axis or 2nd data field
Bit 0 = A axis or 1st data field

Data Fields Format

Data fields must be consistent with the format byte and the axes byte. For example, the command "PR 1000,, -500" would be:

A7 02 00 05 03 E8 FE 0C

where A7 is the command number for PR

02 specifies 2 bytes for each data field

00 coordinated motion is not active for PR

05 specifies bit 0 is active for A axis and bit 2 is active for C axis ($2^0 + 2^2=5$)

03 E8 represents 1000

FE OC represents -500

Example

The command "STABC" to stop motion on just axis A, B, and C would be:

A1 00 00 07

where A1 is the command number for ST

00 specifies 0 data fields

00 specifies the command does not apply to the coordinated motion

07 specifies stop A (bit 0), B (bit 1) and C (bit 2) ($2^0+2^1+2^2 =7$)

For more information and a complete list of all Galil binary commands, please refer to the Optima Series Command Reference at http://www.galilmc.com/support/manuals/manc2000.pdf.

Controller Event Interrupts and User Interrupts

The DMC-18x2 provides a hardware interrupt line that will, when enabled, interrupt the PC bus, which will allow the controller to notify the host application of particular events occurring on the controller. Interrupts free the host from having to poll for the occurrence of certain events such as motion complete or excess position error.

The DMC-18x2 uses only one of the PC's interrupts; however, it is possible to interrupt on multiple conditions. For this reason, the controller provides a status byte register that contains a byte designating each condition.

The DMC-18x2 provides an interrupt buffer that is 16 deep. This allows for multiple interrupt conditions to be stored in sequence of occurrence without loss of data.

The DMC-18x2 provides two command forms of interrupt functionality, EI and UI. Specific interrupt conditions can be enabled using the EI command, or explicit user defined interrupts can be sent using the UI command.

Enabling Event Interrupts (EI command)

To enable certain conditions, use the command EIm,n. Where the first field "m" represents a 16-bit value of conditions described in the table below. For example, to enable interrupts on X and Y motion complete and position error, set EI515 (i.e. $515=2^0+2^1+2^9$). Once the EI command is enabled for a specific condition, an interrupt will occur for every instance of that condition, except for the items marked with an asterisk (*), they must be re-enabled after every occurrence.

Bit Number	Condition
0	X motion complete
1	Y motion complete
2	Z motion complete
3	W motion complete
4	E motion complete
5	F motion complete
6	G motion complete
7	H motion complete
8	All axes motion complete
9	Excess position error*
10	Limit switch
11	Watchdog timer
12	Reserved
13	Application program stopped
14	Command done †
15	Inputs* (uses n for mask)

†Not used when using new version 7 drivers.

The argument "n" enables interrupts for the first 8 general inputs. To enable interrupts for the desired inputs, set bit 15 of the "m" argument, then set the desired inputs using the 8-bit mask for the "n" argument. For example, to enable interrupt on inputs 1-4, set EI32768,15. Note that the input interrupts must be reset for all inputs after any input has caused an interrupt.

Bit number	Input
0	Input 1
1	Input 2
2	Input 3
3	Input 4
4	Input 5
5	Input 6
6	Input 7
7	Input 8

User Interrupts (UI command)
The DMC-18x2 also provides 16 User Interrupts which can be sent by executing the command UIn to the DMC-18x2, where n is an integer between 0 and 15. The UI command does not require the EI command. UI commands are useful in DMC programs to let the host application know that certain points within the DMC program have occurred.

Servicing Interrupts

Once an interrupt occurs, the host computer sends an associated Status Byte along with the interrupt vector. The Status Byte returned denotes what condition has occurred, as described in the table below.

Status Byte (hex)	Condition
00	No interrupt
D9	Watchdog timer activated
DA	Command done
DB	Application program done
F0 thru FF	User interrupt
E1 thru E8	Input interrupt
C0	Limit switch occurred
C8	Excess position error
D8	All axis motion complete
D7	H axis motion complete
D6	G axis motion complete
D5	F axis motion complete
D4	E axis motion complete
D3	W axis motion complete
D2	Z axis motion complete
D1	Y axis motion complete
D0	X axis motion complete

The recommended method to utilize the interrupts in a host application is to use a pre-defined interrupt service routine. Where the event routine, on interrupt, will automatically execute and return the Status Byte. For example, when using the ActiveX toolkit DMCShell control with VB, the DMCShell1_DMCInterrupt() event procedure (shown below) will automatically execute and return the StatusByte in the argument. This StausByte can then be used in a case structure as the key to notify the host application of a specific event or condition.

In this VB example below, the event procedure will display a message box every time the X-axis motion is complete, assuming the command EI1 was sent to the controller. Note: the argument is returned as 208 since the status byte is returned as an integer (i.e. D0 hex = 208 decimal).

```
Private Sub DMCShell1_DMCInterrupt(StatusByte As Integer)
      If StatusByte = 208 Then
            MsgBox "X axis complete"
      End If
End Sub
```

Hardware Level Communications for PCI

This section of the chapter describes in detail the structures used to communicate with the DMC-18x2 controller at the register interface level. The information in this section is intended for advanced programmers with extensive knowledge of PCI bus operation.

Communications with the DMC-18x2

For main bi-directional communication, the DMC-18x2 features a 512 character write FIFO buffer, and a 512 character read buffer. This permits sending commands at high speeds ahead of their actual processing by the DMC-18x2.

Note: This chapter provides an in-depth look at how the controller communicates over the PCI bus at the register interface level. For most users, we recommend using the drivers supplied by Galil to provide the necessary tools for communicating with the controller.

Determining the Base Address

The base address "N" is assigned its value by the BIOS and/or Operating System. The FIFO address N is referenced in the PCI configuration space at BAR2 (offset 18H). The following PCI information (HEX) can be used to identify the DMC-18x2 controller:

PCI Device Identification

DEVICE ID	VENDOR ID	SUBSYSTEM ID	SUBSYSTEM VENDOR ID
9050H	10B5H	1842	1079H

Communication Registers

The DMC-18x2 provides three registers used for communication. The READ register and WRITE register occupy address N and the CONTROL register occupies address N+1 in the I/O space. The READ register is used for receiving data from the DMC-18x2. The WRITE register is used to send data to the DMC-18x2. The CONTROL register may be read or written to and is used for controlling communication, flags and interrupts.

Register	Description	Address	Read/Write
READ	for receiving data	N	Read only
WRITE	for transmitting data	N	Write only
CONTROL	for status control	N+1	Read and Write

Simplified Communication Procedure

The simplest approach for communicating with the DMC-18x2 is to check bits 5 and 6 of the CONTROL register at address N+1.

Status Bit	Action	Logic State	Meaning
5	READ	0	Data to be read
5	READ	1	No data to be read
6	READ	0	Buffer not full, OK to write up to 16 characters
6	READ	1	Buffer full. Do not send data

Read Procedure

To receive data from the DMC-18x2, read the control register at address N+1 and check bit 5. If bit 5 is zero, the DMC-18x2 has data to be read in the READ register at address N. Bit 5 must be checked

for every character read and should be read until it signifies empty. Reading data from the READ register when the register is empty will result in reading an FF hex.

Write Procedure

To send data to the DMC-18x2, read the control register at address N+1 and check bit 6. If bit 6 is zero, the DMC-18x2 FIFO buffer is not almost full and up to 16 characters may be written to the WRITE register at address N. If bit 6 is one, the buffer is almost full and no additional data should be sent. The size of the buffer may be changed (see "Changing Full Flags" below).

Any high-level computer language such as C, Basic, Pascal or Assembly may be used to communicate with the DMC-18x2 as long as the READ/WRITE procedure is followed as described above. Example software drivers are contained on the COM-DISK from Galil.

Advanced Communication Techniques

Changing Full Flags

The Full flag (Bit 6 of the control register) can be configured to change states at a different level from the default level of 16 characters.

The level, m, can be changed from 16 up to 256 in multiples of 16 as follows:

1. Write a 5 to the control register at address N+1.
2. Write the number m-16 to the control register where m is the desired Almost Full level between 16 and 256.

For example, to extend the Almost Full level to 256 bytes, write a 5 to address N+1. Then write a 240 to address N+1.

Clearing FIFO Buffer

The FIFO buffer may be cleared by writing the following sequence:

Read N+1 address

Send 01H to N+1 address

Send 80H to N+1 address

Send 01H to N+1 address

Send 80H to N+1 address

Read N+1 address (Bit 7 will be 1)

It is a good idea to clear any control data before attempting this procedure. Send a no-op instruction, by reading N+1 address, before you start. All data, including data from the DMC-18x2, will then be cleared.

Clearing the FIFO is useful for emergency resets or Abort. For example, to Reset the controller, clear the FIFO, then send the RS command.

Data Record

DATA TYPE	ITEM	BLOCK
UB	1st byte of header	Header

UB	2nd byte of header	Header
UB	3rd byte of header	Header
UB	4rth byte of header	Header
UW	sample number	I block
UB	general input 0	I block
UB	general input 1	I block
UB	general input 2	I block
UB	general input 3	I block
UB	general input 4	I block
UB	general input 5	I block
UB	general input 6	I block
UB	general input 7	I block
UB	general input 8	I block
UB	general input 9	I block
UB	general output 0	I block
UB	general output 1	I block
UB	general output 2	I block
UB	general output 3	I block
UB	general output 4	I block
UB	general output 5	I block
UB	general output 6	I block
UB	general output 7	I block
UB	general output 8	I block
UB	general output 9	I block
UB	error code	I block
UB	general status	I block
UW	segment count of coordinated move for S plane	S block
UW	coordinated move status for S plane	S block
SL	distance traveled in coordinated move for S plane	S block
UW	segment count of coordinated move for T plane	T block
UW	coordinated move status for T plane	T block
SL	distance traveled in coordinated move for T plane	T block
UW	x,a axis status	A block
UB	x,a axis switches	A block
UB	x,a axis stopcode	A block
SL	x,a axis reference position	A block
SL	x,a axis motor position	A block
SL	x,a axis position error	A block
SL	x,a axis auxiliary position	A block
SL	x,a axis velocity	A block
SW	x,a axis torque	A block
UW	y,b axis status	B block
UB	y,b axis switches	B block
UB	y,b axis stopcode	B block
SL	y,b axis reference position	B block

SL	y,b axis motor position	B block
SL	y,b axis position error	B block
SL	y,b axis auxiliary position	B block
SL	y,b axis velocity	B block
SW	y,b axis torque	B block
UW	z,c axis status	C block
UB	z,c axis switches	C block
UB	z,c axis stopcode	C block
SL	z,c axis reference position	C block
SL	z,c axis motor position	C block
SL	z,c axis position error	C block
SL	z,c axis auxiliary position	C block
SL	z,c axis velocity	C block
SW	z,c axis torque	C block
UW	w,d axis status	D block
UB	w,d axis switches	D block
UB	w,d axis stopcode	D block
SL	w,d axis reference position	D block
SL	w,d axis motor position	D block
SL	w,d axis position error	D block
SL	w,d axis auxiliary position	D block
SL	w,d axis velocity	D block
SW	w,d axis torque	D block
UW	e axis status	E block
UB	e axis switches	E block
UB	e axis stopcode	E block
SL	e axis reference position	E block
SL	e axis motor position	E block
SL	e axis position error	E block
SL	e axis auxiliary position	E block
SL	e axis velocity	E block
SW	e axis torque	E block
UW	f axis status	F block
UB	f axis switches	F block
UB	f axis stopcode	F block
SL	f axis reference position	F block
SL	f axis motor position	F block
SL	f axis position error	F block
SL	f axis auxiliary position	F block
SL	f axis velocity	F block
SW	f axis torque	F block
UW	g axis status	G block
UB	g axis switches	G block
UB	g axis stopcode	G block
SL	g axis reference position	G block

SL	g axis motor position	G block
SL	g axis position error	G block
SL	g axis auxiliary position	G block
SL	g axis velocity	G block
SW	g axis torque	G block
UW	h axis status	H block
UB	h axis switches	H block
UB	h axis stopcode	H block
SL	h axis reference position	H block
SL	h axis motor position	H block
SL	h axis position error	H block
SL	h axis auxiliary position	H block
SL	h axis velocity	H block
SW	h axis torque	H block

Explanation of Status Information and Axis Switch Information

General Status Information (1 Byte)

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Program Running	N/A	N/A	N/A	N/A	N/A	Trace on	Echo On

Axis Switch Information (1 Byte)

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Latch Occurred	State of Latch Input	N/A	N/A	State of Forward Limit	State of Reverse Limit	State of Home Input	SM Jumper Installed

Axis Status Information (1 Word)

BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
Move in Progress	Mode of Motion PA or PR	Mode of Motion PA only	(FE) Find Edge in Progress	Home (HM) in Progress	1st Phase of HM complete	2nd Phase of HM complete or FI command issued	Mode of Motion Coord. Motion

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Negative Direction Move	Mode of Motion Contour	Motion is slewing	Motion is stopping due to ST of Limit Switch	Motion is making final decel.	Latch is armed	Off-On-Error Armed	Motor Off

Coordinated Motion Status Information for S or T Plane (2 Byte)

BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
Move in Progress	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
N/A	N/A	Motion is slewing	Motion is stopping due to ST or Limit Switch	Motion is making final decel.	N/A	N/A	N/A

Notes Regarding Velocity, Torque and Analog Input Data

The velocity information that is returned in the data record is 64 times larger than the value returned when using the command TV (Tell Velocity). See command reference for more information about TV.

The torque information is represented as a number in the range of +/-32544. Maximum negative torque of –9.9982 V is represented by –32544. Maximum positive torque of 9.9982 V is represented by 32544. Torque information is then scaled linearly as 1v=~3255.

The analog input is stored as a 16-bit value (+/-32768), which represents an analog voltage range of +/- 10V.

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Chapter 5 Command Basics

Introduction

The DMC-18x2 provides over 100 commands for specifying motion and machine parameters. Commands are included to initiate action, interrogate status and configure the digital filter. These commands can be sent in ASCII or binary.

In ASCII, the DMC-18x2 instruction set is BASIC-like and easy to use. Instructions consist of two uppercase letters that correspond phonetically with the appropriate function. For example, the instruction BG begins motion, and ST stops the motion. In binary, commands are represented by a binary code ranging from 80 to FF.

ASCII commands can be sent "live" over the bus for immediate execution by the DMC-18x2, or an entire group of commands can be downloaded into the DMC-18x2 memory for execution at a later time. Combining commands into groups for later execution is referred to as Applications Programming and is discussed in the following chapter. Binary commands cannot be used in application programs.

This section describes the DMC-18x2 instruction set and syntax. A summary of commands as well as a complete listing of all DMC-18x2 instructions is included in the *Command Reference*.

Command Syntax - ASCII

DMC-18x2 instructions are represented by two ASCII upper case characters followed by applicable arguments. A space may be inserted between the instruction and arguments. A semicolon or <enter> is used to terminate the instruction for processing by the DMC-18x2 command interpreter. Note: If you are using a Galil terminal program, commands will not be processed until an <enter> command is given. This allows the user to separate many commands on a single line and not begin execution until the user gives the <enter> command.

IMPORTANT: All DMC-18x2 commands are sent in upper case.

For example, the command

PR 4000 <enter> Position relative

PR is the two character instruction for position relative. 4000 is the argument which represents the length of the move in counts. The <enter> terminates the instruction. The space between PR and 4000 is optional.

When specifying data for the X,Y,Z and W axes, commas are used to separate the axis' parameters. If no data is specified for an axis, a comma is still needed as a place holder - see below. If no data is specified for an axis, the previous value is maintained. The space between the data and instruction is optional.

To view the current values for each command, type the command followed by a ? for each axis requested. This is interrogation. Not all commands can be interrogated. Refer to the Command Reference to determine whether or not a command can be interrogated.

PR 1000	Specify X only as 1000
PR ,2000	Specify Y only as 2000
PR ,,3000	Specify Z only as 3000
PR ,,,4000	Specify W only as 4000
PR 2000, 4000,6000, 8000	Specify X Y Z and W
PR ,8000,,9000	Specify Y and W only
PR ?,?,?,?	Request X,Y,Z,W values
PR ,?	Request Y value only

The DMC-18x2 provides an alternative method for specifying data. Here data is specified individually using a single axis specifier such as X,Y,Z or W. An equals sign is used to assign data to that axis. For example:

PRX=1000	Specify a position relative movement for the X axis of 1000
ACY=200000	Specify acceleration for the Y axis as 200000

Instead of data, some commands request action to occur on an axis or group of axes. For example, STXY stops motion on both the X and Y axes. Commas are not required in this case since the particular axis is specified by the appropriate letter X Y Z or W. If no parameters follow the instruction, action will take place on all axes. Here are some examples of syntax for requesting action:

BG X	Begin X only
BG Y	Begin Y only
BG XYZW	Begin all axes
BG YW	Begin Y and W only
BG	Begin all axes

Coordinated Motion with more than 1 axis

When requesting action for coordinated motion, the letter S or T is used to specify the coordinated motion. S and T refer to the two coordinate systems that can be used on the card. To specify the desired coordinate system, refer to the command CA in the Command Reference. For example:

BG S	Begin coordinated sequence on S coordinate system
BG SW	Begin coordinated sequence on S and motion on W axis
BG T	Begin coordinated sequence on T coordinate system

Command Syntax - Binary

Some commands have an equivalent binary value. Binary communication mode can be executed much faster than ASCII commands. Binary format can only be used when commands are sent from the PC and cannot be embedded in an application program.

Binary Command Format

All binary commands have a 4 byte header and are followed by data fields. The 4 bytes are specified in hexadecimal format.

Header Format:

Byte 1 specifies the command number between 80 and FF. The complete binary command number table is listed below.

Byte 2 specifies the # of bytes in each field as 0,1,2,4 or 6 as follows:

00	No datafields (i.e. SH or BG)
01	One byte per field
02	One word (2 bytes per field)
04	One long word (4 bytes) per field
06	Galil real format (4 bytes integer and 2 bytes fraction)

Byte 3 specifies whether the command applies to a coordinated move as follows:

00	No coordinated motion movement
01	Coordinated motion movement

For example, the command STS designates motion to stop on a vector motion. The third byte for the equivalent binary command would be 01.

Byte 4 specifies the axis # or data field as follows

Bit 7 = 8th data field

Bit 6 = 7th data field

Bit 5 = 6th data field

Bit 4 = 5th data field

Bit 3 = D axis or 4th data field

Bit 2 = C axis or 3rd data field

Bit 1 = B axis or 2nd data field

Bit 0 = A axis or 1st data field

Datafields Format

Datafields must be consistent with the format byte and the axes byte. For example, the command PR 1000,, -500 would be

A7 02 00 05 03 E8 FE 0C

where A7 is the command number for PR

02 specifies 2 bytes for each data field

00 S is not active for PR

05 specifies bit 0 is active for A axis and bit 2 is active for C axis ($2^0 + 2^2=5$)

03 E8 represents 1000

FE OC represents -500

Example

The command ST XYZS would be

A1 00 01 07

where A1 is the command number for ST

00 specifies 0 data fields

01 specifies stop the coordinated axes S

07 specifies stop X (bit 0), Y (bit 1) and Z (bit 2) $2^0+2^1+2^3 =7$

Binary command table

COMMAND	NO.	COMMAND	NO.	COMMAND	NO.
reserved	80	reserved	ac	reserved	d6
KP	81	reserved	ad	reserved	d7
KI	82	reserved	ae	RP	d8
KD	83	reserved	af	TP	d9
AF	85	LM	b0	TE	da
KF	86	LI	b1	TD	db
PL	87	VP	b2	TV	dc
ER	88	CR	a3	RL	dd
IL	89	TN	b4	TT	de
TL	8a	LE, VE	b5	TS	df
MT	8b	VT	b6	TI	e0
CE	8c	VA	b7	SC	e1
OE	8d	VD	b8	reserved	e2
FL	8e	VS	b9	reserved	e3
BL	8f	VR	ba	reserved	e4
AC	90	reserved	bb	TM	e5
DC	91	reserved	bc	CN	e6
SP	92	CM	bd	LZ	e7
IT	93	CD	be	OP	e8
FA	94	DT	bf	OB	e9
FV	95	ET	c0	SB	ea
GR	96	EM	c1	CB	eb
DP	97	EP	c2	I I	ec
DE	98	EG	c3	EI	ed
OF	99	EB	c4	AL	ee
GM	9a	EQ	c5	reserved	ef
reserved	9b	EC	c6	reserved	f0
reserved	9c	reserved	c7	reserved	f1
reserved	9d	AM	c8	reserved	f2

reserved	9e	MC	c9	reserved	f3
reserved	9f	TW	ca	reserved	f4
BG	a0	MF	cb	reserved	f5
ST	a1	MR	cc	reserved	f6
AB	a2	AD	cd	reserved	f7
HM	a3	AP	ce	reserved	f8
FE	a4	AR	cf	reserved	f9
FI	a5	AS	d0	reserved	fa
PA	a6	AI	d1	reserved	fb
PR	a7	AT	d2	reserved	fc
JG	a8	WT	d3	reserved	fd
MO	a9	WC	d4	reserved	fe
SH	aa	reserved	d5	reserved	ff
reserved	ab				

Controller Response to DATA

The DMC-18x2 returns a : for valid commands.

The DMC-18x2 returns a ? for invalid commands.

For example, if the command BG is sent in lower case, the DMC-18x2 will return a ?.

:bg <enter>	invalid command, lower case
?	DMC-18x2 returns a ?

When the controller receives an invalid command the user can request the error code. The error code will specify the reason for the invalid command response. To request the error code type the command: TC1 For example:

TC1 <enter>	Tell Code command
1 Unrecognized command	Returned response

There are many reasons for receiving an invalid command response. The most common reasons are: unrecognized command (such as typographical entry or lower case), command given at improper time (such as during motion), or a command out of range (such as exceeding maximum speed). A complete listing of all codes can be found in the Command Reference under TC.

Interrogating the Controller

Interrogation Commands

The DMC-18x2 has a set of commands that directly interrogate the controller. When the command is entered, the requested data is returned in decimal format on the next line followed by a carriage return and line feed. The format of the returned data can be changed using the Position Format (PF), Variable Format (VF) and Leading Zeros (LZ) command. See Chapter 7 and the Command Reference.

Summary of Interrogation Commands

RP	Report Command Position

RL	Report Latch
^R ^V	Firmware Revision Information
SC	Stop Code
TB	Tell Status
TC	Tell Error Code
TD	Tell Dual Encoder
TE	Tell Error
TI	Tell Input
TP	Tell Position
TR	Trace
TS	Tell Switches
TT	Tell Torque
TV	Tell Velocity

For example, the following example illustrates how to display the current position of the X axis:

TP X <enter>	Tell position X
0000000000	Controllers Response
TP XY <enter>	Tell position X and Y
0000000000,0000000000	Controllers Response

Interrogating Current Commanded Values.

Most commands can be interrogated by using a question mark (?) as the axis specifier. Type the command followed by a ? for each axis requested.

PR ?,?,?,?	Request X,Y,Z,W values
PR ,?	Request Y value only

The controller can also be interrogated with operands.

Operands

Most DMC-18x2 commands have corresponding operands that can be used for interrogation. Operands must be used inside of valid DMC expressions. For example, to display the value of an operand, the user could use the command:

MG ‘operand’ where ‘operand’ is a valid DMC operand

All of the command operands begin with the underscore character (_). For example, the value of the current position on the X axis can be assigned to the variable ‘V’ with the command:

V=_TPX

The Command Reference denotes all commands which have an equivalent operand as "Used as an Operand". Also, see description of operands in Chapter 7.

Command Summary

For a complete command summary, see the *Command Reference*.

Chapter 6 Programming Motion

Overview

The DMC-18x2 provides several modes of motion, including independent positioning and jogging, coordinated motion, electronic cam motion, and electronic gearing. Each one of these modes is discussed in the following sections.

The DMC-1812 is a single axis controller and uses X-axis motion only. Likewise, the DMC-1822 uses X and Y, the DMC-1832 uses X,Y,and Z, and the DMC-1842 uses X,Y,Z,and W.

The example applications described below will help guide you to the appropriate mode of motion.

EXAMPLE APPLICATION	MODE OF MOTION	COMMANDS
Absolute or relative positioning where each axis is independent and follows prescribed velocity profile.	Independent Axis Positioning	PA,PR SP,AC,DC
Velocity control where no final endpoint is prescribed. Motion stops on Stop command.	Independent Jogging	JG AC,DC ST
Motion Path described as incremental position points versus time.	Contour Mode	CM CD DT WC
2,3 or 4 axis coordinated motion where path is described by linear segments.	Linear Interpolation	LM LI,LE VS,VR VA,VD
2-D motion path consisting of arc segments and linear segments, such as engraving or quilting.	Coordinated Motion	VM VP CR VS,VR VA,VD VE
Third axis must remain tangent to 2-D motion path, such as knife cutting.	Coordinated motion with tangent axis specified	VM VP CR VS,VA,VD TN VE

Electronic gearing where slave axes are scaled to master axis which can move in both directions.	Electronic Gearing	GA GR GM (if gantry)
Master/slave where slave axes must follow a master such as conveyer speed.	Electronic Gearing	GA GR
Moving along arbitrary profiles or mathematically prescribed profiles such as sine or cosine trajectories.	Contour Mode	CM CD DT WC
Teaching or Record and Play Back	Contour Mode with Automatic Array Capture	CM CD DT WC RA RD RC
Backlash Correction	Dual Loop	DV
Following a trajectory based on a master encoder position	Electronic Cam	EA EM EP ET EB EG EQ
Smooth motion while operating in independent axis positioning	Independent Motion Smoothing	IT
Smooth motion while operating in vector or linear interpolation positioning	Vector Smoothing	VT
Smooth motion while operating with stepper motors	Stepper Motor Smoothing	KS
Gantry - two axes are coupled by gantry	Gantry Mode	GR GM

Independent Axis Positioning

In this mode, motion between the specified axes is independent, and each axis follows its own profile. The user specifies the desired absolute position (PA) or relative position (PR), slew speed (SP), acceleration ramp (AC), and deceleration ramp (DC), for each axis. On begin (BG), the DMC-18x2 profiler generates the corresponding trapezoidal or triangular velocity profile and position trajectory. The controller determines a new command position along the trajectory every sample period until the specified profile is complete. Motion is complete when the last position command is sent by the DMC-18x2 profiler. Note: The actual motor motion may not be complete when the profile has been completed, however, the next motion command may be specified.

The Begin (BG) command can be issued for all axes either simultaneously or independently. XYZ or W axis specifiers are required to select the axes for motion. When no axes are specified, this causes motion to begin on all axes.

The speed (SP) and the acceleration (AC) can be changed at any time during motion, however, the deceleration (DC) and position (PR or PA) cannot be changed until motion is complete. Remember, motion is complete (AM) when the profiler is finished, not when the actual motor is in position. The

Stop command (ST) can be issued at any time to decelerate the motor to a stop before it reaches its final position.

An incremental position movement (IP) may be specified during motion as long as the additional move is in the same direction. Here, the user specifies the desired position increment, n. The new target is equal to the old target plus the increment, n. Upon receiving the IP command, a revised profile will be generated for motion towards the new end position. The IP command does not require a begin. Note: If the motor is not moving, the IP command is equivalent to the PR and BG command combination.

Command Summary - Independent Axis

COMMAND	DESCRIPTION
PR x,y,z,w	Specifies relative distance
PA x,y,z,w	Specifies absolute position
SP x,y,z,w	Specifies slew speed
AC x,y,z,w	Specifies acceleration rate
DC x,y,z,w	Specifies deceleration rate
BG XYZW	Starts motion
ST XYZW	Stops motion before end of move
IP x,y,z,w	Changes position target
IT x,y,z,w	Time constant for independent motion smoothing
AM XYZW	Trippoint for profiler complete
MC XYZW	Trippoint for "in position"

The lower case specifiers (x,y,z,w) represent position values for each axis.

The DMC-18x2 also allows use of single axis specifiers such as PRY=2000

Operand Summary - Independent Axis

OPERAND	DESCRIPTION
_ACx	Return acceleration rate for the axis specified by ‘x’
_DCx	Return deceleration rate for the axis specified by ‘x’
_SPx	Returns the speed for the axis specified by ‘x’
_PAx	Returns current destination if ‘x’ axis is moving, otherwise returns the current commanded position if in a move.
_PRx	Returns current incremental distance specified for the ‘x’ axis

Example - Absolute Position Movement

PA 10000,20000	Specify absolute X,Y position
AC 1000000,1000000	Acceleration for X,Y
DC 1000000,1000000	Deceleration for X,Y
SP 50000,30000	Speeds for X,Y
BG XY	Begin motion

Example - Multiple Move Sequence

Required Motion Profiles:

X-Axis	2000 counts	Position
	15000 count/sec	Speed
	500000 counts/sec^2	Acceleration & Deceleration
Y-Axis	500 counts	Position
	10000 count/sec	Speed
	500000 counts/sec^2	Acceleration & Deceleration
Z-Axis	100 counts	Position
	5000 counts/sec	Speed
	500000 counts/sec	Acceleration & Deceleration

This example will specify a relative position movement on X, Y and Z axes. The movement on each axis will be separated by 20 msec. Fig. 6.1 shows the velocity profiles for the X,Y and Z axis.

#A	Begin Program
PR 2000,500,100	Specify relative position movement of 2000, 500 and 100 counts for X,Y and Z axes.
SP 20000,10000,5000	Specify speed of 20000, 10000, and 5000 counts / sec
AC 500000,500000,500000	Specify acceleration of 500000 counts / sec^2 for all axes
DC 500000,500000,500000	Specify deceleration of 500000 counts / sec^2 for all axes
BG X	Begin motion on the X axis
WT 20	Wait 20 msec
BG Y	Begin motion on the Y axis
WT 20	Wait 20 msec
BG Z	Begin motion on Z axis
EN	End Program

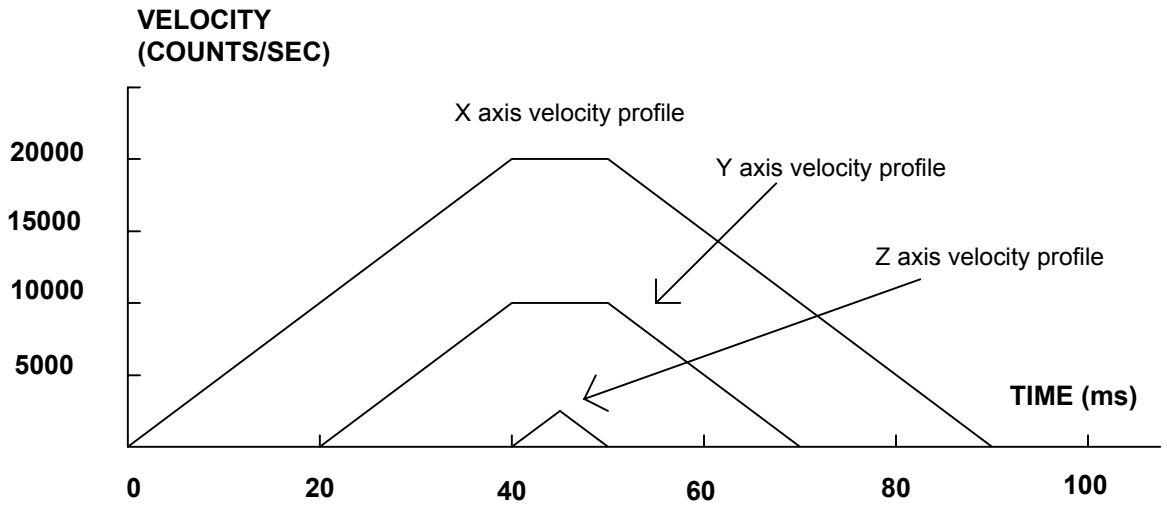


Figure 6.1 - Velocity Profiles of XYZ

Notes on fig 6.1: The X and Y axis have a 'trapezoidal' velocity profile, while the Z axis has a 'triangular' velocity profile. The X and Y axes accelerate to the specified speed, move at this constant speed, and then decelerate such that the final position agrees with the command position, PR. The Z axis accelerates, but before the specified speed is achieved, must begin deceleration such that the axis will stop at the commanded position. All 3 axes have the same acceleration and deceleration rate, hence, the slope of the rising and falling edges of all 3 velocity profiles are the same.

Independent Jogging

The jog mode of motion is very flexible because speed, direction and acceleration can be changed during motion. The user specifies the jog speed (JG), acceleration (AC), and the deceleration (DC) rate for each axis. The direction of motion is specified by the sign of the JG parameters. When the begin command is given (BG), the motor accelerates up to speed and continues to jog at that speed until a new speed or stop (ST) command is issued. If the jog speed is changed during motion, the controller will make an accelerated (or decelerated) change to the new speed.

An instant change to the motor position can be made with the use of the IP command. Upon receiving this command, the controller commands the motor to a position which is equal to the specified increment plus the current position. This command is useful when trying to synchronize the position of two motors while they are moving.

Note that the controller operates as a closed-loop position controller while in the jog mode. The DMC-18x2 converts the velocity profile into a position trajectory and a new position target is generated every sample period. This method of control results in precise speed regulation with phase lock accuracy.

Command Summary - Jogging

COMMAND	DESCRIPTION
AC x,y,z,w	Specifies acceleration rate
BG XYZW	Begins motion
DC x,y,z,w	Specifies deceleration rate
IP x,y,z,w	Increments position instantly
IT x,y,z,w	Time constant for independent motion smoothing

JG +/-x,y,z,w	Specifies jog speed and direction
ST XYZW	Stops motion

Parameters can be set with individual axis specifiers such as JGY=2000 (set jog speed for Y axis to 2000) or ACYH=400000 (set acceleration for Y and H axes to 400000).

Operand Summary - Independent Axis

OPERAND	DESCRIPTION
_ACx	Return acceleration rate for the axis specified by 'x'
_DCx	Return deceleration rate for the axis specified by 'x'
_SPx	Returns the jog speed for the axis specified by 'x'
_TVx	Returns the actual velocity of the axis specified by 'x' (averaged over .25 sec)

Example - Jog in X only

Jog X motor at 50000 count/s. After X motor is at its jog speed, begin jogging Z in reverse direction at 25000 count/s.

```
#A
AC 20000,,20000          Specify X,Z acceleration of 20000 cts / sec
DC 20000,,20000          Specify X,Z deceleration of 20000 cts / sec
JG 50000,,-25000         Specify jog speed and direction for X and Z axis
BG X                     Begin X motion
AS X                     Wait until X is at speed
BG Z                     Begin Z motion
EN
```

Linear Interpolation Mode

The DMC-18x2 provides a linear interpolation mode for 2 or more axes. In linear interpolation mode, motion between the axes is coordinated to maintain the prescribed vector speed, acceleration, and deceleration along the specified path. The motion path is described in terms of incremental distances for each axis. An unlimited number of incremental segments may be given in a continuous move sequence, making the linear interpolation mode ideal for following a piece-wise linear path. There is no limit to the total move length.

The LM command selects the Linear Interpolation mode and axes for interpolation. For example, LM YZ selects only the Y and Z axes for linear interpolation.

When using the linear interpolation mode, the LM command only needs to be specified once unless the axes for linear interpolation change.

Specifying Linear Segments

The command LI x,y,z,w specifies the incremental move distance for each axis. This means motion is prescribed with respect to the current axis position. Up to 511 incremental move segments may be given prior to the Begin Sequence (BGS or BGT) command. Once motion has begun, additional LI segments may be sent to the controller.

The clear sequence (CS) command can be used to remove LI segments stored in the buffer prior to the start of the motion. To stop the motion, use the instructions STS, STT, or AB. The command, ST, causes a decelerated stop. The command, AB, causes an instantaneous stop and aborts the program, and the command AB1 aborts the motion only.

The Linear End (LE) command must be used to specify the end of a linear move sequence. This command tells the controller to decelerate to a stop following the last LI command. If an LE command is not given, an Abort AB1 must be used to abort the motion sequence.

It is the responsibility of the user to keep enough LI segments in the DMC-18x2 sequence buffer to ensure continuous motion. If the controller receives no additional LI segments and no LE command, the controller will stop motion instantly at the last vector. There will be no controlled deceleration. LM? or _LM returns the available spaces for LI segments that can be sent to the buffer. 511 returned means the buffer is empty and 511 LI segments can be sent. A zero means the buffer is full and no additional segments can be sent. As long as the buffer is not full, additional LI segments can be sent at PC bus speeds.

The instruction _CS returns the number of the segment being processed. As the segments are processed, _CS increases, starting at zero. This function allows the host computer to determine which segment is being completed.

Additional Commands

The commands VS n, VA n, and VD n are used to specify the vector speed, acceleration, and deceleration. The DMC-18x2 computes the vector speed based on the axes specified in the LM mode. For example, LM XYZ designates linear interpolation for the X,Y and Z axes. The vector speed for this example would be computed using the equation:

$VS^2=XS^2+YS^2+ZS^2$, where XS, YS and ZS are the speed of the X,Y and Z axes.

The controller computes the vector speed with the axis specifications from LM.

VT is used to set the S-curve smoothing constant for coordinated moves. The command AV n is the 'After Vector' trippoint which halts program execution until the vector distance of n has been reached.

An Example of Linear Interpolation Motion:

#LMOVE	label
DP 0,0	Define position of X and Y axes to be 0
LMXY	Define linear mode between X and Y axes.
LI 5000,0	Specify first linear segment
LI 0,5000	Specify second linear segment
LE	End linear segments
VS 4000	Specify vector speed
BGS	Begin motion sequence
AV 4000	Set trippoint to wait until vector distance of 4000 is reached
VS 1000	Change vector speed
AV 5000	Set trippoint to wait until vector distance of 5000 is reached
VS 4000	Change vector speed
EN	Program end

In this example, the XY system is required to perform a 90° turn. In order to slow the speed around the corner, we use the AV 4000 trippoint, which slows the speed to 1000 count/s. Once the motors reach the corner, the speed is increased back to 4000 cts / s.

Specifying Vector Speed for Each Segment

The instruction VS has an immediate effect and, therefore, must be given at the required time. In some applications, such as CNC, it is necessary to attach various speeds to different motion segments. This can be done with two functions: < n and > m

For example: LI x,y,z,w < n >m

The first command, < n, is equivalent to commanding VSn at the start of the given segment and will cause an acceleration toward the new commanded speed, subject to the other constraints.

The second function, > m, requires the vector speed to reach the value m at the end of the segment. Note that the function > m may start the deceleration within the given segment or during previous segments, as needed to meet the final speed requirement, under the given values of VA and VD.

Note, however, that the controller works with one > m command at a time. As a consequence, one function may be masked by another. For example, if the function >100000 is followed by >5000, and the distance for deceleration is not sufficient, the second condition will not be met. The controller will attempt to lower the speed to 5000.

As an example, consider the following program.

#ALT	Label for alternative program
DP 0,0	Define Position of X and Y axis to be 0
LMXY	Define linear mode between X and Y axes.
LI 4000,0 <4000 >1000	Specify first linear segment with a vector speed of 4000 and end speed 1000
LI 1000,1000 < 4000 >1000	Specify second linear segment with a vector speed of 4000 and end speed 1000
LI 0,5000 < 4000 >1000	Specify third linear segment with a vector speed of 4000 and end speed 1000
LE	End linear segments
BGS	Begin motion sequence
EN	Program end

Changing Feedrate:

The command VR n allows the feedrate, VS, to be scaled between 0 and 10 with a resolution of .0001. This command takes effect immediately and causes VS to be scaled. VR also applies when the vector speed is specified with the '<' operator. This is a useful feature for feedrate override. VR does not ratio the accelerations. For example, VR .5 results in the specification VS 2000 to be divided in half.

Command Summary - Linear Interpolation

COMMAND	DESCRIPTION
LM xyzw	Specify axes for linear interpolation
LM?	Returns number of available spaces for linear segments in DMC-18x2 sequence buffer. Zero means buffer full. 511 means buffer empty.
LI x,y,z,w < n	Specify incremental distances relative to current position, and assign vector speed n.
VS n	Specify vector speed
VA n	Specify vector acceleration
VD n	Specify vector deceleration
VR n	Specify the vector speed ratio
BGS or BGT	Begin Linear Sequence (on S or T coordinate system)
CS	Clear sequence
LE	Linear End- Required at end of LI command sequence

LE?	Returns the length of the vector (resets after 2147483647)
AMS or AMT	Trippoint for After Sequence complete (on S or T coordinate system)
AV n	Trippoint for After Relative Vector distance, n
VT	Motion smoothing constant for vector moves

Operand Summary - Linear Interpolation

OPERAND	DESCRIPTION
_AV	Return distance traveled
_CS	Segment counter - returns number of the segment in the sequence being processed, starting at zero.
_LE	Returns length of vector (resets after 2147483647)
_LM	Returns number of available spaces for linear segments in DMC-18x2 sequence buffer. Zero means buffer full. 511 means buffer empty.
_VPx	Return the absolute coordinate of the last data point along the trajectory. (x=X,Y,Z or W)

To illustrate the ability to interrogate the motion status, consider the first motion segment of our example, #LMOVE, where the X axis moves toward the point X=5000. Suppose that when X=3000, the controller is interrogated using the command 'MG _AV'. The returned value will be 3000. The value of _CS, _VPX and _VPY will be zero.

Now suppose that the interrogation is repeated at the second segment when Y=2000. The value of _AV at this point is 7000, _CS equals 1, _VPX=5000 and _VPY=0.

Example - Linear Move

Make a coordinated linear move in the ZW plane. Move to coordinates 40000,30000 counts at a vector speed of 100000 counts/sec and vector acceleration of 1000000 counts/sec^2.

LM ZW	Specify axes for linear interpolation
LI,,40000,30000	Specify ZW distances
LE	Specify end move
VS 100000	Specify vector speed
VA 1000000	Specify vector acceleration
VD 1000000	Specify vector deceleration
BGS	Begin sequence

Note that the above program specifies the vector speed, VS, and not the actual axis speeds VZ and VW. The axis speeds are determined by the DMC-18x2 from:

$$VS = \sqrt{VZ^2 + VW^2}$$

The resulting profile is shown in Figure 6.2.

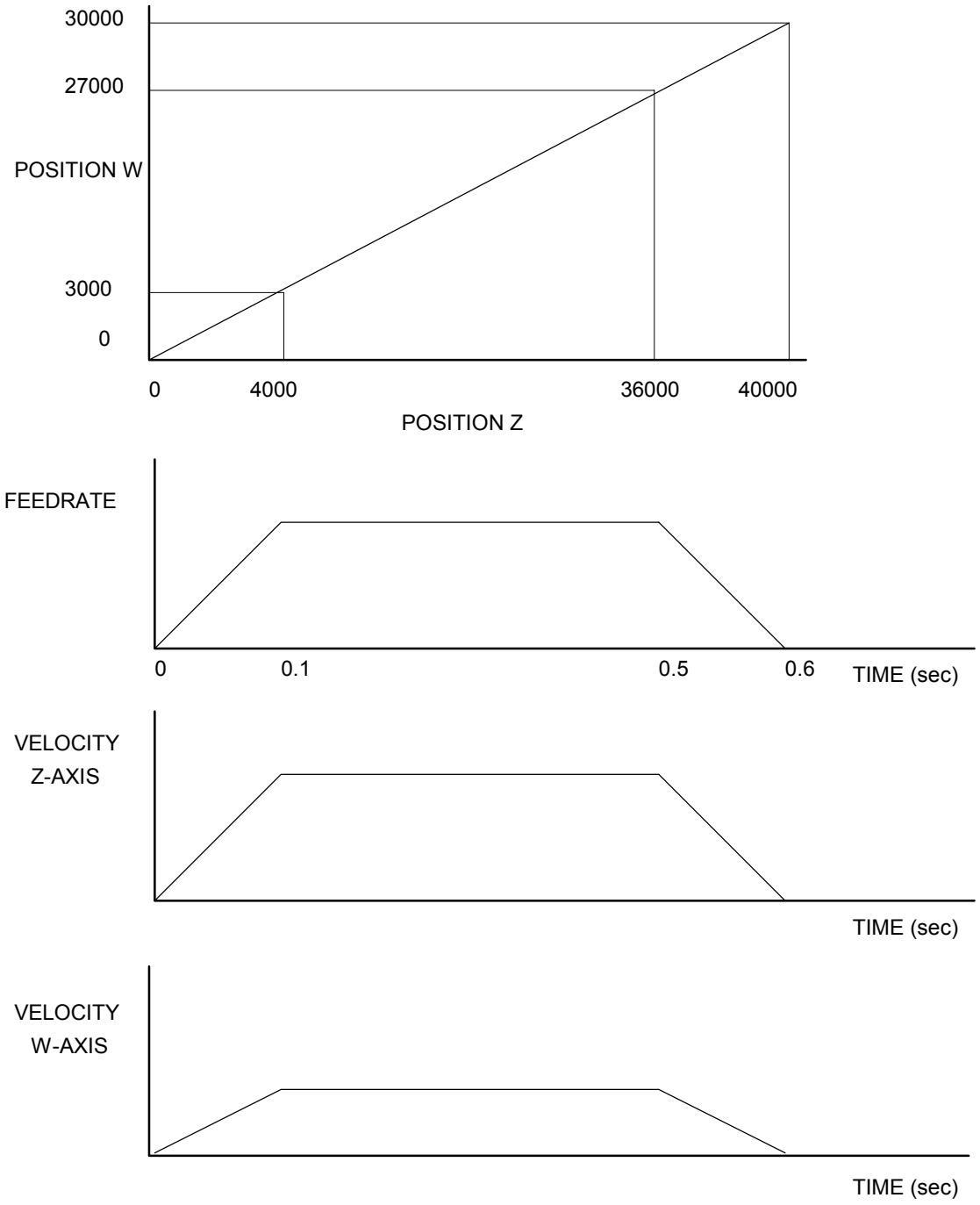


Figure 6.2 - Linear Interpolation

Example - Multiple Moves

This example makes a coordinated linear move in the XY plane. The Arrays VX and VY are used to store 750 incremental distances which are filled by the program #LOAD.

#LOAD	Load Program
DM VX [750],VY [750]	Define Array
COUNT=0	Initialize Counter
N=10	Initialize position increment
#LOOP	LOOP
VX [COUNT]=N	Fill Array VX
VY [COUNT]=N	Fill Array VY
N=N+10	Increment position
COUNT=COUNT+1	Increment counter
JP #LOOP,COUNT<750	Loop if array not full
#A	Label
CAS	Specify coordinate system S
LM XY	Specify linear mode for XY
COUNT=0	Initialize array counter
#LOOP2;JP#LOOP2,_LM=0	If sequence buffer full, wait
JS#C,COUNT=500	Begin motion on 500th segment
LI VX[COUNT],VY[COUNT]	Specify linear segment
COUNT=COUNT+1	Increment array counter
JP #LOOP2,COUNT<750	Repeat until array done
LE	End Linear Move
AMS	After Move sequence done
MG "DONE"	Send Message
EN	End program
#C;BGS;EN	Begin Motion Subroutine

Vector Mode: Linear and Circular Interpolation Motion

The DMC-18x2 allows a long 2-D path consisting of linear and arc segments to be prescribed. Motion along the path is continuous at the chosen vector speed even at transitions between linear and circular segments. The DMC-18x2 performs all the complex computations of linear and circular interpolation, freeing the host PC from this time intensive task.

The coordinated motion mode is similar to the linear interpolation mode. Any pair of two axes may be selected for coordinated motion consisting of linear and circular segments. In addition, a third axis can be controlled such that it remains tangent to the motion of the selected pair of axes. Note that only one pair of axes can be specified for coordinated motion at any given time.

The command VM m,n,p where ‘m’ and ‘n’ are the coordinated pair and p is the tangent axis (Note: the commas which separate m, n, and p are not necessary). For example, VM XWZ selects the XW axes for coordinated motion and the Z-axis as the tangent.

Specifying Vector Segments

The motion segments are described by two commands; VP for linear segments and CR for circular segments. Once a set of linear segments and/or circular segments have been specified, the sequence is

ended with the command VE. This defines a sequence of commands for coordinated motion. Immediately prior to the execution of the first coordinated movement, the controller defines the current position to be zero for all movements in a sequence. Note: This 'local' definition of zero does not affect the absolute coordinate system or subsequent coordinated motion sequences.

The command, VP x,y specifies the coordinates of the end points of the vector movement with respect to the starting point. Non-sequential axes do not require comma delimitation. The command, CR r,θ,δ define a circular arc with a radius r, starting angle of θ, and a traversed angle δ. The notation for θ is that zero corresponds to the positive horizontal direction, and for both θ and δ, the counter-clockwise (CCW) rotation is positive.

Up to 511 segments of CR or VP may be specified in a single sequence and must be ended with the command VE. The motion can be initiated with a Begin Sequence (BGS or BGT) command. Once motion starts, additional segments may be added.

The Clear Sequence (CS) command can be used to remove previous VP and CR commands which were stored in the buffer prior to the start of the motion. To stop the motion, use the instructions STS or AB1. ST stops motion at the specified deceleration. AB1 aborts the motion instantaneously.

The Vector End (VE) command must be used to specify the end of the coordinated motion. This command tells the controller to decelerate to a stop following the last motion in the sequence. If a VE command is not given, an Abort (AB1) must be used to abort the coordinated motion sequence.

The user must keep enough motion segments in the DMC-18x2 sequence buffer to ensure continuous motion. If the controller receives no additional motion segments and no VE command, the controller will stop motion instantly at the last vector. There will be no controlled deceleration. LM? or _LM returns the available spaces for motion segments that can be sent to the buffer. 511 returned means the buffer is empty and 511 segments can be sent. A zero means the buffer is full and no additional segments can be sent. As long as the buffer is not full, additional segments can be sent at the PCI bus speed.

The operand _CS can be used to determine the value of the segment counter.

Additional commands

The commands VS n, VA n and VD n are used for specifying the vector speed, acceleration, and deceleration.

VT is the motion smoothing constant used for coordinated motion.

Specifying Vector Speed for Each Segment:

The vector speed may be specified by the immediate command VS. It can also be attached to a motion segment with the instructions

VP x,y < n >m

CR r,θ,δ < n >m

The first parameter, <n, is equivalent to commanding VSn at the start of the given segment and will cause an acceleration toward the new commanded speeds, subjects to the other constraints.

The second parameter, > m, requires the vector speed to reach the value m at the end of the segment. Note that the function > m may start the deceleration within the given segment or during previous segments, as needed to meet the final speed requirement, under the given values of VA and VD.

Note, however, that the controller works with one > m command at a time. As a consequence, one function may be masked by another. For example, if the function >100000 is followed by >5000, and the distance for deceleration is not sufficient, the second condition will not be met. The controller will attempt to lower the speed to 5000, but will reach that at a different point.

Changing Feedrate:

The command VR n allows the feedrate, VS, to be scaled from 0 and 10 times with a resolution of .0001. This command takes effect immediately and causes VS scaled. VR also applies when the vector speed is specified with the '<' operator. This is a useful feature for feedrate override. VR does not ratio the accelerations. For example, VR .5 results in the specification VS 2000 act as VS 1000.

Compensating for Differences in Encoder Resolution:

By default, the DMC-18x2 uses a scale factor of 1:1 for the encoder resolution when used in vector mode. If this is not the case, the command, ES can be used to scale the encoder counts. The ES command accepts two arguments which represent the ratio of the encoder resolutions. For more information refer to ES in the Command Reference.

Trippoints:

The AV n command is the After Vector trippoint, which waits for the vector relative distance of n to occur before executing the next command in a program.

Tangent Motion:

Several applications, such as cutting, require a third axis (i.e. a knife blade), to remain tangent to the coordinated motion path. To handle these applications, the DMC-18x2 allows one axis to be specified as the tangent axis. The VM command provides parameter specifications for describing the coordinated axes and the tangent axis.

VM m,n,p	m,n specifies coordinated axes p specifies the tangent axis such as X,Y,Z,W p=N turns off tangent axis

Before the tangent mode can operate, it is necessary to assign an axis via the VM command and define its offset and scale factor via the TN m,n command. m defines the scale factor in counts/degree and n defines the tangent axis encoder position that corresponds to zero degrees. The operand _TN can be used to return the initial position of the tangent axis. Refer to TN in the Command Reference.

Example:

Assume an XY table that has the Z-axis controlling a knife. The Z-axis has a 2000 quad counts/rev encoder and has been initialized after power-up to point the knife in the +Y direction. A 180° circular cut is desired, with a radius of 3000, center at the origin and a starting point at (3000,0). The motion is CCW, ending at (-3000,0). Note that the 0° position in the XY plane is in the +X direction. This corresponds to the position -500 in the Z-axis, and defines the offset. The motion has two parts. First, X,Y and Z are driven to the starting point, and later, the cut is performed. Assume that the knife is engaged with output bit 0.

#EXAMPLE	Example program
CAS	Select coordinate system S
VM XYZ	XY coordinate with Z as tangent
TN 2000/360,-500	2000/360 counts/degree, position -500 is 0 degrees in XY plane
CR 3000,0,180	3000 count radius, start at 0 and go to 180 CCW
VE	End vector
CB0	Disengage knife
PA 3000,0,_TN	Move X and Y to starting position, move Z to initial tangent position
BG XYZ	Start the move to get into position

AM XYZ	When the move is complete
SB0	Engage knife
WT50	Wait 50 msec for the knife to engage
BGS	Do the circular cut
AMS	After the coordinated move is complete
CB0	Disengage knife
MG "ALL DONE"	
EN	End program

Command Summary - Coordinated Motion Sequence

COMMAND	DESCRIPTION.
VM m,n	Specifies the axes for the planar motion where m and n represent the planar axes and p is the tangent axis.
VP m,n	Return coordinate of last point, where m=X,Y,Z or W.
CR r,θ,δ	Specifies arc segment where r is the radius, θ is the starting angle and δ is the travel angle. Positive direction is CCW.
VS n	Specify vector speed or feedrate of sequence.
VA n	Specify vector acceleration along the sequence.
VD n	Specify vector deceleration along the sequence.
VR n	Specify vector speed ratio.
CAS or CAT	Choose coordinate system (S or T).
BGS or BGT	Begin motion sequence on S or T coordinate system.
CS	Clear sequence.
AV n	Trippoint for After Relative Vector distance, n.
AMS	Holds execution of next command until Motion Sequence is complete.
TN m,n	Tangent scale and offset.
ES m,n	Ellipse scale factor.
VT	S curve smoothing constant for coordinated moves.
LM?	Return number of available spaces for linear and circular segments in DMC-18x2 sequence buffer. Zero means buffer is full. 512 means buffer is empty.

Operand Summary - Coordinated Motion Sequence

OPERAND	DESCRIPTION
_VPM	The absolute coordinate of the axes at the last intersection along the sequence.
_AV	Distance traveled.
_LM	Number of available spaces for linear and circular segments in DMC-18x2 sequence buffer. Zero means buffer is full. 512 means buffer is empty.
_CS	Segment counter - Number of the segment in the sequence, starting at zero.
_VE	Vector length of coordinated move sequence.

When AV is used as an operand, _AV returns the distance traveled along the sequence.

The operands _VPX and _VPY can be used to return the coordinates of the last point specified along the path.

Example:

Traverse the path shown in Fig. 6.3. Feedrate is 20000 counts/sec. Plane of motion is XY

VM XY	Specify motion plane
VS 20000	Specify vector speed
VA 1000000	Specify vector acceleration
VD 1000000	Specify vector deceleration
VP -4000,0	Segment AB
CR 1500,270,-180	Segment BC
VP 0,3000	Segment CD
CR 1500,90,-180	Segment DA
VE	End of sequence
BGS	Begin Sequence

The resulting motion starts at the point A and moves toward points B, C, D, A. Suppose that we interrogate the controller when the motion is halfway between the points A and B.

The value of _AV is 2000

The value of _CS is 0

_VPX and _VPY contain the absolute coordinate of the point A

Suppose that the interrogation is repeated at a point, halfway between the points C and D.

The value of _AV is 4000+1500π+2000=10,712

The value of _CS is 2

_VPX,_VPY contain the coordinates of the point C

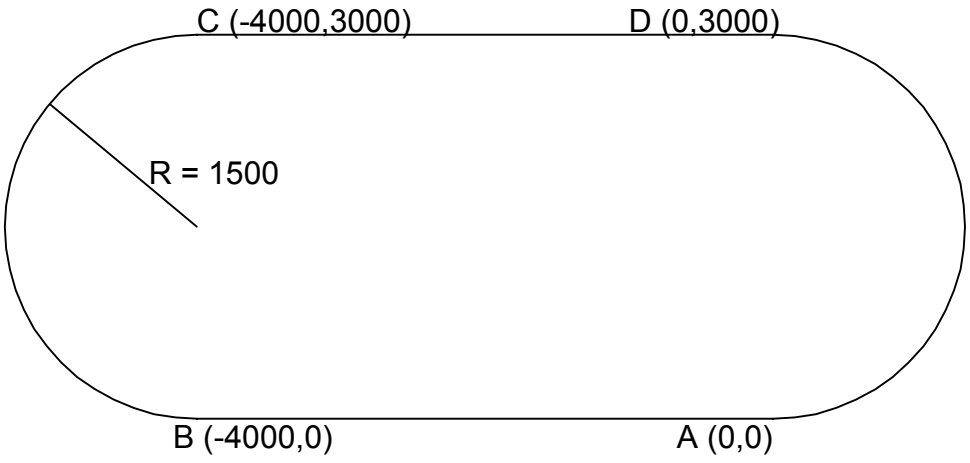


Figure 6.3 - The Required Path

Electronic Gearing

This mode allows multiple axes to be electronically geared to some master axes. The masters may rotate in both directions and the geared axes will follow at the specified gear ratio. The gear ratio may be different for each axis and changed during motion.

The command GA specifies the master axes. GR x,y,z,w specifies the gear ratios for the slaves where the ratio may be a number between +/-127.9999 with a fractional resolution of .0001. There are two modes: standard gearing and gantry mode. The gantry mode is enabled with the command GM. GR 0,0,0,0 turns off gearing in both modes. A limit switch or ST command disables gearing in the standard mode but not in the gantry mode.

The command GM x,y,z,w selects the axes to be controlled under the gantry mode. The parameter 1 enables gantry mode, and 0 disables it.

GR causes the specified axes to be geared to the actual position of the master. The master axis is commanded with motion commands such as PR, PA, or JG.

When the master axis is driven by the controller in the jog mode or an independent motion mode, it is possible to define the master as the command position of that axis, rather than the actual position. The designation of the commanded position master is by the letter C. For example, GACX indicates that the gearing is the commanded position of X.

An alternative gearing method is to synchronize the slave motor to the commanded vector motion of several axes performed by GAS. For example, if the X and Y motor form a circular motion, the Z axis may move in proportion to the vector move. Similarly, if X,Y, and Z perform a linear interpolation move, W can be geared to the vector move.

Electronic gearing allows the geared motor to perform a second independent or coordinated move in addition to the gearing. For example, when a geared motor follows a master at a ratio of 1:1, it may be advanced an additional distance with PR, JG, VP, or LI commands.

Command Summary - Electronic Gearing

COMMAND	DESCRIPTION
GA n	Specifies master axes for gearing where: n = X,Y,Z or W or A,B,C,D for main encoder as master
	n = CX,CY,CZ, CW **or** CA, CB,CC,CD for commanded position.
	n = S vector move as master
GR x,y,z,w	Sets gear ratio for slave axes. 0 disables electronic gearing for specified axis.
GM x,y,z,w	X = 1 sets gantry mode, 0 disables gantry mode
MR x,y,z,w	Trippoint for reverse motion past specified value. Only one field may be used.
MF x,y,z,w	Trippoint for forward motion past specified value. Only one field may be used.

Example - Simple Master Slave

Master axis moves 10000 counts at slew speed of 100000 counts/sec. Y is defined as the master. X,Z,W are geared to master at ratios of 5,-.5 and 10 respectively.

GA Y,,Y,Y	Specify master axes as Y
GR 5,,-.5,10	Set gear ratios
PR ,10000	Specify Y position
SP ,100000	Specify Y speed
BGY	Begin motion

Example - Electronic Gearing

Objective: Run two geared motors at speeds of 1.132 and -0.045 times the speed of an external master. The master is driven at speeds between 0 and 1800 RPM (2000 counts/rev encoder).

Solution: Use a DMC-1832 controller, where the Z-axis is the master and X and Y are the geared axes.

MO Z	Turn Z off, for external master
GA Z, Z	Specify Z as the master axis for both X and Y.
GR 1.132,-.045	Specify gear ratios

Now suppose the gear ratio of the X-axis is to change on-the-fly to 2. This can be achieved by commanding:

GR 2	Specify gear ratio for X axis to be 2

Example - Gantry Mode

In applications where both the master and the follower are controlled by the DMC-18x2 controller, it may be desired to synchronize the follower with the commanded position of the master, rather than the actual position. This eliminates the possibility of an oscillation on the master passing the oscillation on to the slave.

For example, assume that a gantry is driven by two axes, X and Y, one on each side. This requires the gantry mode for strong coupling between the motors. The X-axis is the master and the Y-axis is the follower. To synchronize Y with the commanded position of X, use the instructions:

GA, CX	Specify the commanded position of X as master for Y.
GR,1	Set gear ratio for Y as 1:1
GM,1	Set gantry mode
PR 3000	Command X motion
BG X	Start motion on X axis

You may also perform profiled position corrections in the electronic gearing mode. Suppose, for example, that you need to advance the slave 10 counts. Simply command

IP ,10	Specify an incremental position movement of 10 on the Y axis.

Under these conditions, this IP command is equivalent to:

PR,10	Specify position relative movement of 10 on the Y axis
BGY	Begin motion on the Y axis

Often the correction is quite large. Such requirements are common when synchronizing cutting knives or conveyor belts.

Example - Synchronize two conveyor belts with trapezoidal velocity correction.

GA,X	Define X as the master axis for Y.
GR,2	Set gear ratio 2:1 for Y
PR,300	Specify correction distance
SP,5000	Specify correction speed
AC,100000	Specify correction acceleration
DC,100000	Specify correction deceleration
BGY	Start correction

Electronic Cam

The electronic cam is a motion control mode which enables the periodic synchronization of several axes of motion. Up to 3 axes can be slaved to one master axis.

The electronic cam is a more general type of electronic gearing which allows a table-based relationship between the axes. It allows synchronizing all the controller axes.

To illustrate the procedure of setting the cam mode, consider the cam relationship for the slave axis Y, when the master is X. Such a graphic relationship is shown in Figure 6.4.

Step 1. Selecting the master axis

The first step in the electronic cam mode is to select the master axis. This is done with the instruction

EAp where p = X,Y,Z,W

p is the selected master axis

For the given example, since the master is x, we specify EAX

Step 2. Specify the master cycle and the change in the slave axis (es).

In the electronic cam mode, the position of the master is always expressed within one cycle. In this example, the position of x is always expressed in the range between 0 and 6000. Similarly, the slave position is also redefined such that it starts at zero and ends at 1500. At the end of a cycle when the master is 6000 and the slave is 1500, the positions of both x and y are redefined as zero. To specify the master cycle and the slave cycle change, we use the instruction EM.

EM x,y,z,w

where x,y,z,w specify the cycle of the master and the total change of the slaves over one cycle.

The cycle of the master is limited to 8,388,607 whereas the slave change per cycle is limited to 2,147,483,647. If the change is a negative number, the absolute value is specified. For the given example, the cycle of the master is 6000 counts and the change in the slave is 1500. Therefore, we use the instruction:

EM 6000,1500

Step 3. Specify the master interval and starting point.

Next we need to construct the ECAM table. The table is specified at uniform intervals of master positions. Up to 256 intervals are allowed. The size of the master interval and the starting point are specified by the instruction:

EP m,n

where m is the interval width in counts, and n is the starting point.

For the given example, we can specify the table by specifying the position at the master points of 0, 2000, 4000 and 6000. We can specify that by

```
EP 2000,0
```

Step 4. Specify the slave positions.

Next, we specify the slave positions with the instruction

```
ET[n]=x,y,z,w
```

where n indicates the order of the point.

The value, n, starts at zero and may go up to 256. The parameters x,y,z,w indicate the corresponding slave position. For this example, the table may be specified by

```
ET[0]=,0
ET[1]=,3000
ET[2]=,2250
ET[3]=,1500
```

This specifies the ECAM table.

Step 5. Enable the ECAM

To enable the ECAM mode, use the command

```
EB n
```

where n=1 enables ECAM mode and n=0 disables ECAM mode.

Step 6. Engage the slave motion

To engage the slave motion, use the instruction

```
EG x,y,z,w
```

where x,y,z,w are the master positions at which the corresponding slaves must be engaged.

If the value of any parameter is outside the range of one cycle, the cam engages immediately. When the cam is engaged, the slave position is redefined, modulo one cycle.

Step 7. Disengage the slave motion

To disengage the cam, use the command

EQ x,y,z,w

where x,y,z,w are the master positions at which the corresponding slave axes are disengaged.

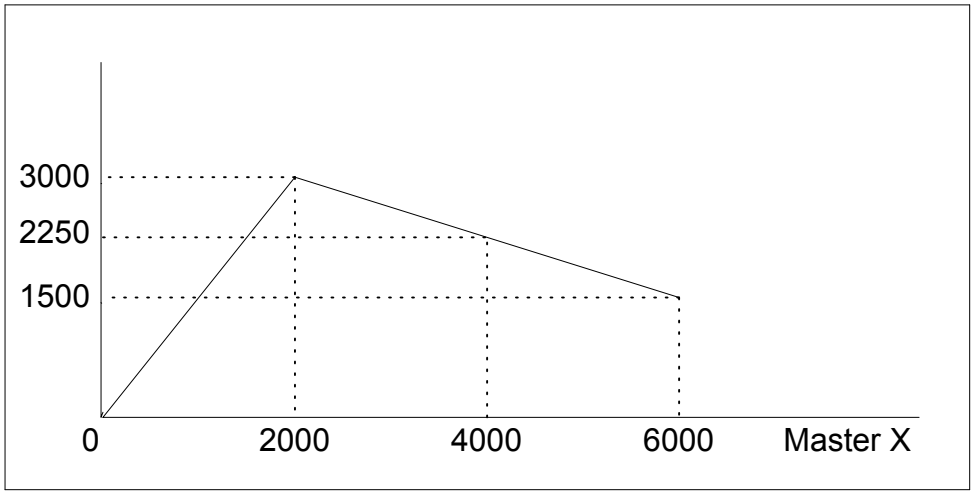


Figure 6.4: Electronic Cam Example

This disengages the slave axis at a specified master position. If the parameter is outside the master cycle, the stopping is instantaneous.

To illustrate the complete process, consider the cam relationship described by

the equation:

$$Y = 0.5 * X + 100 \sin (0.18*X)$$

where X is the master, with a cycle of 2000 counts.

The cam table can be constructed manually, point by point, or automatically by a program. The following program includes the set-up.

The instruction EAX defines X as the master axis. The cycle of the master is

2000. Over that cycle, Y varies by 1000. This leads to the instruction EM 2000,1000.

Suppose we want to define a table with 100 segments. This implies increments of 20 counts each. If the master points are to start at zero, the required instruction is EP 20,0.

The following routine computes the table points. As the phase equals 0.18X and X varies in increments of 20, the phase varies by increments of 3.6°. The program then computes the values of Y according to the equation and assigns the values to the table with the instruction ET[N] = ,Y.

Instruction	Interpretation
#SETUP	Label
EAX	Select X as master
EM 2000,1000	Cam cycles
EP 20,0	Master position increments
N = 0	Index
#LOOP	Loop to construct table from equation
P = N∗3.6	Note 3.6 = 0.18∗20
S = @SIN [P] ∗100	Define sine position
Y = N ∗10+S	Define slave position
ET [N] =, Y	Define table
N = N+1	
JP #LOOP, N<=100	Repeat the process
EN	

Now suppose that the slave axis is engaged with a start signal, input 1, but that both the engagement and disengagement points must be done at the center of the cycle: X = 1000 and Y = 500. This implies that Y must be driven to that point to avoid a jump.

This is done with the program:

Instruction	Interpretation
#RUN	Label
EB1	Enable cam
PA,500	starting position
SP,5000	Y speed
BGY	Move Y motor
AM	After Y moved
AI1	Wait for start signal
EG,1000	Engage slave
AI - 1	Wait for stop signal
EQ,1000	Disengage slave
EN	End

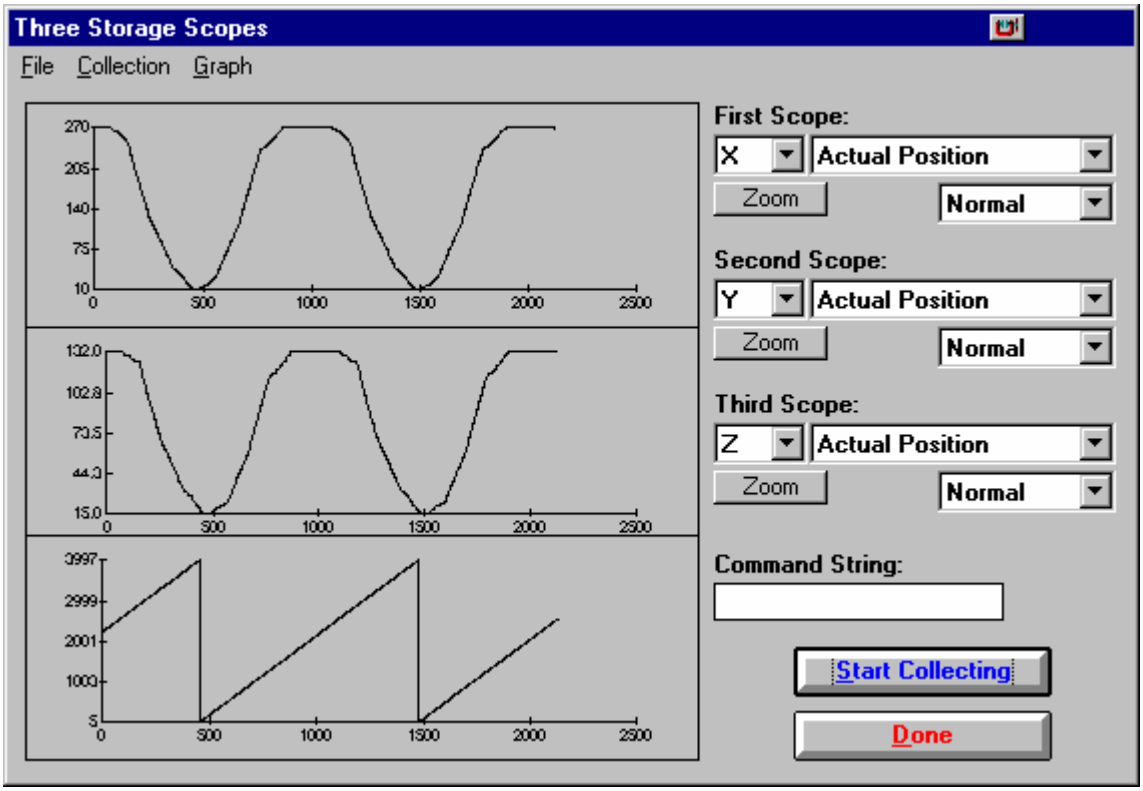
Command Summary – Electronic CAM

COMMAND	DESCRIPTION
EA p	Specifies master axes for electronic cam where: P = X,Y,Z or W or A,B,C,D,E,F,G,H for main encoder as master
EB n	Enables the ECAM
EC n	ECAM counter – sets the index into the ECAM table
EG x,y,z,w	Engages ECAM
EM x,y,z,w	Specifies the change in position for each axis of the CAM cycle
EP m,n	Defines CAM table entry size and offset
EQ m,n	Disengages ECAM at specified position
ET[n]	Defines the ECAM table entries
EW	Widen segment (see Application Note #2444)
EY	Set ECAM cycle count

The following example illustrates a cam program with a master axis, Z, and two slaves, X and Y.

Instruction	Interpretation
#A;V1=0	Label; Initialize variable
PA 0,0;BGXY;AMXY	Go to position 0,0 on X and Y axes
EA Z	Z axis as the Master for ECAM
EM 0,0,4000	Change for Z is 4000, zero for X, Y
EP400,0	ECAM interval is 400 counts with zero start
ET[0]=0,0	When master is at 0 position; 1st point.
ET[1]=40,20	2nd point in the ECAM table
ET[2]=120,60	3rd point in the ECAM table
ET[3]=240,120	4th point in the ECAM table
ET[4]=280,140	5th point in the ECAM table
ET[5]=280,140	6th point in the ECAM table
ET[6]=280,140	7th point in the ECAM table
ET[7]=240,120	8th point in the ECAM table
ET[8]=120,60	9th point in the ECAM table
ET[9]=40,20	10th point in the ECAM table
ET[10]=0,0	Starting point for next cycle
EB 1	Enable ECAM mode
JGZ=4000	Set Z to jog at 4000
EG 0,0	Engage both X and Y when Master = 0
BGZ	Begin jog on Z axis
#LOOP;JP#LOOP,V1=0	Loop until the variable is set
EQ2000,2000	Disengage X and Y when Master = 2000
MF,, 2000	Wait until the Master goes to 2000
ST Z	Stop the Z axis motion
EB 0	Exit the ECAM mode
EN	End of the program

The above example shows how the ECAM program is structured and how the commands can be given to the controller. The next page provides the results captured by the WSDK program. This shows how the motion will be seen during the ECAM cycles. The first graph is for the X axis, the second graph shows the cycle on the Y axis and the third graph shows the cycle of the Z axis.



Contour Mode

The DMC-18x2 also provides a contouring mode. This mode allows any arbitrary position curve to be prescribed for 1 to 4 axes. This is ideal for following computer generated paths such as parabolic, spherical or user-defined profiles. The path is not limited to straight line and arc segments and the path length may be infinite.

Specifying Contour Segments

The Contour Mode is specified with the command, CM. For example, CMXZ specifies contouring on the X and Z axes. Any axes that are not being used in the contouring mode may be operated in other modes.

A contour is described by position increments which are described with the command, CD x,y,z,w over a time interval, DT n. The parameter, n, specifies the time interval. The time interval is defined as 2^n ms, where n is a number between 1 and 8. The controller performs linear interpolation between the specified increments, where one point is generated for each millisecond.

Consider, for example, the trajectory shown in Fig. 6.5. The position X may be described by the points:

Point 1	X=0 at T=0ms
Point 2	X=48 at T=4ms
Point 3	X=288 at T=12ms
Point 4	X=336 at T=28ms

The same trajectory may be represented by the increments

Increment 1	DX=48	Time Increment =4	DT=2
Increment 2	DX=240	Time Increment =8	DT=3
Increment 3	DX=48	Time Increment =16	DT=4

When the controller receives the command to generate a trajectory along these points, it interpolates linearly between the points. The resulting interpolated points include the position 12 at 1 msec, position 24 at 2 msec, etc.

The programmed commands to specify the above example are:

#A	
CMX	Specifies X axis for contour mode
DT 2	Specifies first time interval, 2^2 ms
CD 48;WC	Specifies first position increment
DT 3	Specifies second time interval, 2^3 ms
CD 240;WC	Specifies second position increment
DT 4	Specifies the third time interval, 2^4 ms
CD 48;WC	Specifies the third position increment
DT0;CD0	Exits contour mode
EN	

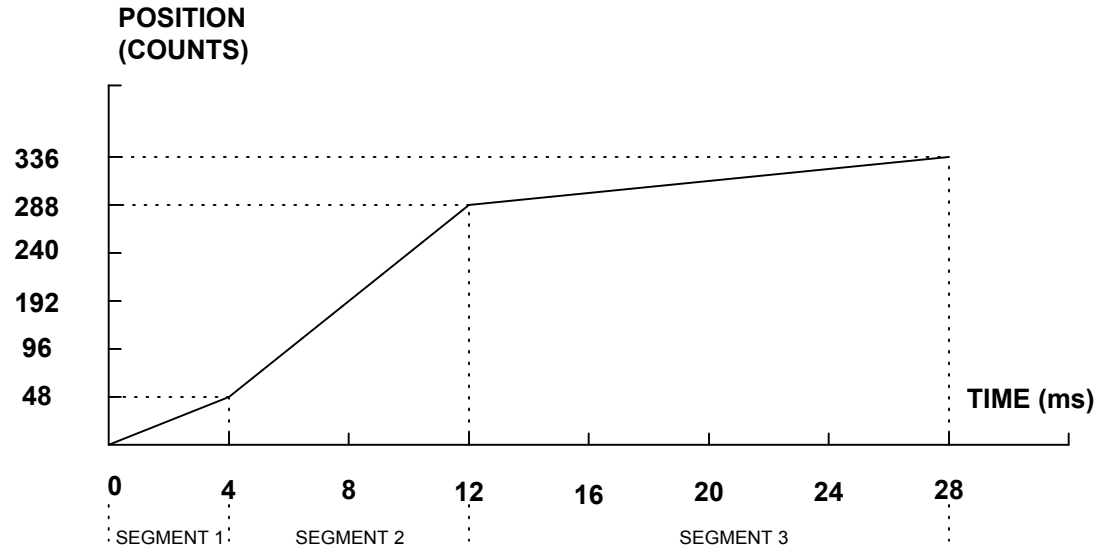


Figure 6.5 - The Required Trajectory

Additional Commands

The command, WC, is used as a trippoint "When Complete" or “Wait for Contour Data”. This allows the DMC-18x2 to use the next increment only when it is finished with the previous one. Zero parameters for DT followed by zero parameters for CD exit the contour mode.

If no new data record is found and the controller is still in the contour mode, the controller waits for new data. No new motion commands are generated while waiting. If bad data is received, the controller responds with a ?.

Command Summary - Contour Mode

COMMAND	DESCRIPTION
CM XYZW	Specifies which axes for contouring mode. Any non-contouring axes may be operated in other modes.
CD x,y,z,w	Specifies position increment over time interval. Range is +/-32,000. Zero ends contour mode.
DT n	Specifies time interval 2^n msec for position increment, where n is an integer between 1 and 8. Zero ends contour mode. If n does not change, it does not need to be specified with each CD.
WC	Waits for previous time interval to be complete before next data record is processed.

General Velocity Profiles

The Contour Mode is ideal for generating an arbitrary velocity profile. The velocity profile can be specified as a mathematical function or as a collection of points.

The design includes two parts: Generating an array with data points and running the program.

Generating an Array - An Example

Consider the velocity and position profiles shown in Fig. 6.6. The objective is to rotate a motor a distance of 6000 counts in 120 ms. The velocity profile is sinusoidal to reduce the jerk and the system vibration. If we describe the position displacement in terms of A counts in B milliseconds, we can describe the motion in the following manner:

$$\omega = (A/B) [1 - \cos (2\pi T/B)]$$

$$\mathbf{X} = (AT/B) - (A/2\pi)\sin (2\pi T/B)$$

Note: ω is the angular velocity; **X** is the position; and T is the variable, time, in milliseconds.

In the given example, A=6000 and B=120, the position and velocity profiles are:

$$\mathbf{X} = 50T - (6000/2\pi) \sin (2\pi\ T/120)$$

Note that the velocity, ω, in count/ms, is

$$\omega = 50 [1 - \cos 2\pi\ T/120]$$

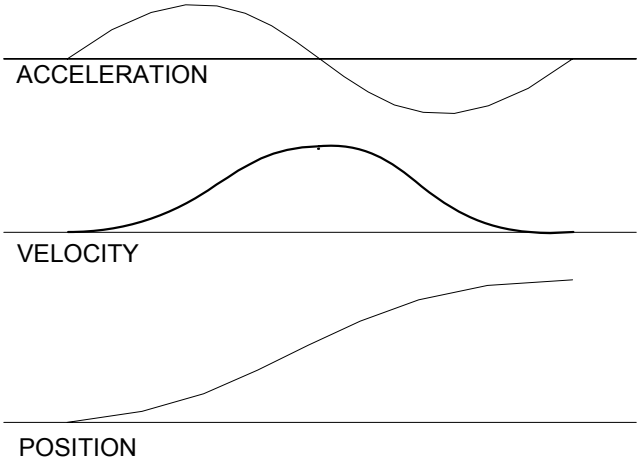


Figure 6.6 - Velocity Profile with Sinusoidal Acceleration

The DMC-18x2 can compute trigonometric functions. However, the argument must be expressed in degrees. Using our example, the equation for X is written as:

X = 50T - 955 sin 3T

A complete program to generate the contour movement in this example is given below. To generate an array, we compute the position value at intervals of 8 ms. This is stored at the array POS. Then, the difference between the positions is computed and is stored in the array DIF. Finally the motors are run in the contour mode.

Contour Mode Example

Instruction	Interpretation
#POINTS	Program defines X points
DM POS[16]	Allocate memory
DM DIF[15]	
C=0	Set initial conditions, C is index
T=0	T is time in ms
#A	
V1=50*T	
V2=3*T	Argument in degrees
V3=-955*@SIN[V2]+V1	Compute position
V4=@INT[V3]	Integer value of V3
POS[C]=V4	Store in array POS
T=T+8	
C=C+1	
JP #A,C<16	

```
#B                      Program to find position differences
C=0
#C
D=C+1
DIF[C]=POS[D]-POS[C]    Compute the difference and store
C=C+1
JP #C,C<15
EN                      End first program
#RUN                    Program to run motor
CMX                     Contour Mode
DT3                     4 millisecond intervals
C=0
#E
CD DIF[C]               Contour Distance is in DIF
WC                      Wait for completion
C=C+1
JP #E,C<15
DT0
CD0                     Stop Contour
EN                      End the program
```

Teach (Record and Play-Back)

Several applications require teaching the machine a motion trajectory. Teaching can be accomplished using the DMC-18x2 automatic array capture feature to capture position data. The captured data may then be played back in the contour mode. The following array commands are used:

DM C[n]	Dimension array
RA C[]	Specify array for automatic record (up to 4)
RD _TPX	Specify data for capturing (such as _TPX or _TPZ)
RC n,m	Specify capture time interval where n is 2n msec, m is number of records to be captured
RC? or _RC	Returns a 1 if recording

Record and Playback Example:

```
#RECORD                 Begin Program
DM XPOS[501]            Dimension array with 501 elements
RA XPOS[]               Specify automatic record
RD _TPX                 Specify X position to be captured
MOX                     Turn X motor off
RC2                     Begin recording; 4 msec interval
#A;JP#A,_RC=1           Continue until done recording
#COMPUTE                Compute DX
DM DX[500]              Dimension Array for DX
```

```
C=0                         Initialize counter
#L                          Label
D=C+1
DELTA=XPOS[D]-XPOS[C]       Compute the difference
DX[C]=DELTA                 Store difference in array
C=C+1                       Increment index
JP #L,C<500                 Repeat until done
#PLAYBCK                    Begin Playback
CMX                         Specify contour mode
DT2                         Specify time increment
I=0                         Initialize array counter
#B                          Loop counter
CD XPOS[I];WC               Specify contour data
I=I+1                       Increment array counter
JP#B, I < 500               Loop until done
DT 0;CD0                    End contour mode
EN                          End program
```

For additional information about automatic array capture, see Chapter 7, Arrays.

Stepper Motor Operation

When configured for stepper motor operation, several commands are interpreted differently than from servo mode. The following describes operation with stepper motors.

Specifying Stepper Motor Operation

In order to command stepper motor operation, the appropriate stepper mode jumpers must be installed. See chapter 2 for this installation.

Stepper motor operation is specified by the command MT. The argument for MT is as follows:

2 specifies a stepper motor with active low step output pulses

-2 specifies a stepper motor with active high step output pulses

2.5 specifies a stepper motor with active low step output pulses and reversed direction

-2.5 specifies a stepper motor with active high step output pulse and reversed direction

Stepper Motor Smoothing

The command, KS, provides stepper motor smoothing. The effect of the smoothing can be thought of as a simple Resistor-Capacitor (single pole) filter. The filter occurs after the motion profiler and has the effect of smoothing out the spacing of pulses for a more smooth operation of the stepper motor. Use of KS is most applicable when operating in full step or half step operation. KS will cause the step pulses to be delayed in accordance with the time constant specified.

When operating with stepper motors, you will always have some amount of stepper motor smoothing, KS. Since this filtering effect occurs after the profiler, the profiler may be ready for additional moves before all of the step pulses have gone through the filter. It is important to consider this effect since steps may be lost if the controller is commanded to generate an additional move before the previous move has been completed. See the discussion below, *Monitoring Generated Pulses vs Commanded Pulses*.

The general motion smoothing command, IT, can also be used. The purpose of the command, IT, is to smooth out the motion profile and decrease 'jerk' due to acceleration.

Monitoring Generated Pulses vs Commanded Pulses

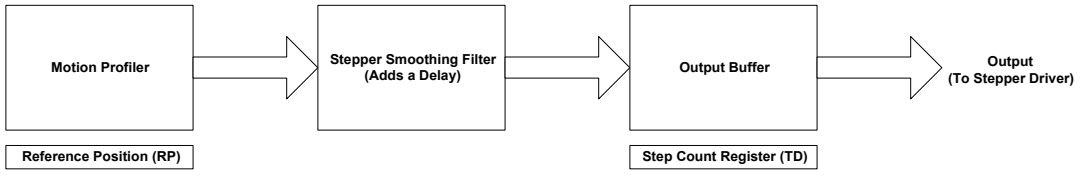
For proper controller operation, it is necessary to make sure that the controller has completed generating all step pulses before making additional moves. This is most particularly important if you are moving back and forth. For example, when operating with servo motors, the trippoint AM (After Motion) is used to determine when the motion profiler is complete and is prepared to execute a new motion command. However when operating in stepper mode, the controller may still be generating step pulses when the motion profiler is complete. This is caused by the stepper motor smoothing filter, KS. To understand this, consider the steps the controller executes to generate step pulses:

First, the controller generates a motion profile in accordance with the motion commands.

Second, the profiler generates pulses as prescribed by the motion profile. The pulses that are generated by the motion profiler can be monitored by the command, RP (Reference Position). RP gives the absolute value of the position as determined by the motion profiler. The command, DP, can be used to set the value of the reference position. For example, DP 0, defines the reference position of the X axis to be zero.

Third, the output of the motion profiler is filtered by the stepper smoothing filter. This filter adds a delay in the output of the stepper motor pulses. The amount of delay depends on the parameter which is specified by the command, KS. As mentioned earlier, there will always be some amount of stepper motor smoothing. The default value for KS is 2 which corresponds to a time constant of 6 sample periods.

Fourth, the output of the stepper smoothing filter is buffered and is available for input to the stepper motor driver. The pulses which are generated by the smoothing filter can be monitored by the command, TD (Tell Dual). TD gives the absolute value of the position as determined by actual output of the buffer. The command, DP sets the value of the step count register as well as the value of the reference position. For example, DP 0, defines the reference position of the X axis to be zero.



Motion Complete Trippoint

When used in stepper mode, the MC command will hold up execution of the proceeding commands until the controller has generated the same number of steps out of the step count register as specified in the commanded position. The MC trippoint (Motion Complete) is generally more useful than the AM trippoint (After Motion) since the step pulses can be delayed from the commanded position due to stepper motor smoothing.

Using an Encoder with Stepper Motors

An encoder may be used on a stepper motor to check the actual motor position with the commanded position. The position of the encoder can be interrogated by using the command TP. The position value can be defined by using the command DE.

Note: Closed loop operation with a stepper motor is not possible outside of the application level.

Command Summary - Stepper Motor Operation

COMMAND	DESCRIPTION
DE	Define Encoder Position (When using an encoder)
DP	Define Reference Position and Step Count Register
IT	Motion Profile Smoothing - Independent Time Constant
KS	Stepper Motor Smoothing
MT	Motor Type (2,-2,2.5 or -2.5 for stepper motors)
RP	Report Commanded Position
TD	Report number of step pulses generated by controller
TP	Tell Position of Encoder

Operand Summary - Stepper Motor Operation

OPERAND	DESCRIPTION
_DEx	Contains the value of the step count register for the ‘x’ axis
_DPx	Contains the value of the encoder for the ‘x’ axis
_ITx	Contains the value of the Independent Time constant for the 'x' axis
_KSx	Contains the value of the Stepper Motor Smoothing Constant for the 'x' axis
_MTx	Contains the motor type value for the 'x' axis
_RPx	Contains the commanded position generated by the profiler for the ‘x’ axis
_TDx	Contains the value of the step count register for the ‘x’ axis
_TPx	Contains the value of the main encoder for the ‘x’ axis

Stepper Position Maintenance Mode (SPM)

The Galil controller can be set into the Stepper Position Maintenance (SPM) mode to handle the event of stepper motor position error. The mode looks at position feedback from the main encoder and compares it to the commanded step pulses. The position information is used to determine if there is any significant difference between the commanded and the actual motor positions. If such error is detected, it is updated into a command value for operator use. In addition, the SPM mode can be used as a method to correct for friction at the end of a microstepping move. This capability provides closed-loop control at the application program level. SPM mode can be used with Galil and non-Galil step drives.

SPM mode is configured, executed, and managed with seven commands. This mode also utilizes the #POSERR automatic subroutine allowing for automatic user-defined handling of an error event.

Internal Controller Commands (user can query):

QS Error Magnitude (pulses)

User Configurable Commands (user can query & change):

OE	Profiler Off-On Error
YA	Step Drive Resolution (pulses / full motor step)
YB	Step Motor Resolution (full motor steps / revolution)
YC	Encoder Resolution (counts / revolution)
YR	Error Correction (pulses)
YS	Stepper Position Maintenance enable, status

A pulse is defined by the resolution of the step drive being used. Therefore, one pulse could be a full step, a half step or a microstep.

When a Galil controller is configured for step motor operation, the step pulse output by the controller is internally fed back to the auxiliary encoder register. For SPM the feedback encoder on the stepper will connect to the main encoder port. Enabling the SPM mode on a controller with YS=1 executes an internal monitoring of the auxiliary and main encoder registers for that axis or axes. Position error is then tracked in step pulses between these two registers (QS command).

$$QS = TD - \frac{TP \times YA \times YB}{YC}$$

Where TD is the auxiliary encoder register(step pulses) and TP is the main encoder register(feedback encoder). Additionally, YA defines the step drive resolution where YA = 1 for full stepping or YA = 2 for half stepping. The full range of YA is up to YA = 9999 for microstepping drives.

Error Limit

The value of QS is internally monitored to determine if it exceeds a preset limit of three full motor steps. Once the value of QS exceeds this limit, the controller then performs the following actions:

The motion is maintained or is stopped, depending on the setting of the OE command. If OE=0 the axis stays in motion, if OE=1 the axis is stopped.

YS is set to 2, which causes the automatic subroutine labeled #POSERR to be executed.

Correction

A correction move can be commanded by assigning the value of QS to the YR correction move command. The correction move is issued only after the axis has been stopped. After an error correction move has completed and QS is less than three full motor steps, the YS error status bit is automatically reset back to 1 indicating a cleared error.

Example: SPM Mode Setup

The following code demonstrates what is necessary to set up SPM mode for a full step drive, a half step drive, and a 1/64th microstepping drive for an axis with a 1.8o step motor and 4000 count/rev encoder. Note the necessary difference is with the YA command.

Full-Stepping Drive, X axis:

```
#SETUP
OE1;            'SET THE PROFILER TO STOP AXIS UPON ERROR
KS16;           'SET STEP SMOOTHING
MT-2;           'MOTOR TYPE SET TO STEPPER
YA1;            'STEP RESOLUTION OF THE FULL-STEP DRIVE
YB200;          'MOTOR RESOLUTION (FULL STEPS PER REVOLUTION)
YC4000;         'ENCODER RESOLUTION (COUNTS PER REVOLUTION)
SHX;            'ENABLE AXIS
WT50;           'ALLOW SLIGHT SETTLE TIME
YS1;            'ENABLE SPM MODE
```

Half-Stepping Drive, X axis:

```
#SETUP
OE1;            'SET THE PROFILER TO STOP AXIS UPON ERROR
KS16;           'SET STEP SMOOTHING
MT-2;           'MOTOR TYPE SET TO STEPPER
YA2;            'STEP RESOLUTION OF THE HALF-STEP DRIVE
YB200;          'MOTOR RESOLUTION (FULL STEPS PER REVOLUTION)
YC4000;         'ENCODER RESOLUTION (COUNTS PER REVOLUTION)
SHX;            'ENABLE AXIS
WT50;           'ALLOW SLIGHT SETTLE TIME
YS1;            'ENABLE SPM MODE
```

1/64th Step Microstepping Drive, X axis:

```
#SETUP
OE1;            'SET THE PROFILER TO STOP AXIS UPON ERROR
KS16;           'SET STEP SMOOTHING
MT-2;           'MOTOR TYPE SET TO STEPPER
YA64;           'STEP RESOLUTION OF THE MICROSTEPPING DRIVE
YB200;          'MOTOR RESOLUTION (FULL STEPS PER REVOLUTION)
```

```
YC4000;          'ENCODER RESOLUTION (COUNTS PER REVOLUTION)
SHX;             'ENABLE AXIS
WT50;            'ALLOW SLIGHT SETTLE TIME
YS1;             'ENABLE SPM MODE
```

Example: Error Correction

The following code demonstrates what is necessary to set up SPM mode for the X axis, detect error, stop the motor, correct the error, and return to the main code. The drive is a full step drive, with a 1.8° step motor and 4000 count/rev encoder.

```
#SETUP
OE1;             'SET THE PROFILER TO STOP AXIS UPON ERROR
KS16;            'SET STEP SMOOTHING
MT-2,-2,-2,-2;   'MOTOR TYPE SET TO STEPPER
YA2;             'STEP RESOLUTION OF THE DRIVE
YB200;           'MOTOR RESOLUTION (FULL STEPS PER REVOLUTION)
YC4000;          'ENCODER RESOLUTION (COUNTS PER REVOLUTION)
SHX;             'ENABLE AXIS
WT100;           'ALLOW SLIGHT SETTLE TIME
YS1;             'ENABLE SPM MODE

#MOTION          'PERFORM MOTION
SP512;           'SET THE SPEED
PR1000;          'PREPARE MODE OF MOTION
BGX;             'BEGIN MOTION
#LOOP;JP#LOOP;   'KEEP THREAD ZERO ALIVE FOR #POSERR TO RUN IN

REM When error occurs, the axis will stop due to OE1.  In
REM #POSERR, query the status YS and the error QS, correct,
REM and return to the main code.

#POSERR;         'AUTOMATIC SUBROUTINE IS CALLED WHEN YS=2
WT100;       'WAIT HELPS USER SEE THE CORRECTION
spsave=_SPX;     'SAVE CURRENT SPEED SETTING
JP#RETURN,_YSX<>2;'RETURN TO THREAD ZERO IF INVALID ERROR
SP64;            'SET SLOW SPEED SETTING FOR CORRECTION
MG"ERROR= ",_QSX
YRX=_QSX;        'ELSE, ERROR IS VALID, USE QS FOR CORRECTION
```

```
MCX;                    'WAIT FOR MOTION TO COMPLETE
MG"CORRECTED, ERROR NOW= ",_QSX
WT100;          'WAIT HELPS USER SEE THE CORRECTION

#RETURN
SPX=spsave;             'RETURN THE SPEED TO PREVIOUS SETTING
RE0;                    'RETURN FROM #POSERR
```

Example: Friction Correction

The following example illustrates how the SPM mode can be useful in correcting for X axis friction after each move when conducting a reciprocating motion. The drive is a 1/64th microstepping drive with a 1.8^{o} step motor and 4000 count/rev encoder.

```
#SETUP;             'SET THE PROFILER TO CONTINUE UPON ERROR
KS16;               'SET STEP SMOOTHING
MT-2,-2,-2,-2;      'MOTOR TYPE SET TO STEPPER
YA64;               'STEP RESOLUTION OF THE MICROSTEPPING DRIVE
YB200;              'MOTOR RESOLUTION (FULL STEPS PER REVOLUTION)
YC4000;             'ENCODER RESOLUTION (COUNTS PER REVOLUTION)
SHX;                'ENABLE AXIS
WT50;               'ALLOW SLIGHT SETTLE TIME
YS1;                'ENABLE SPM MODE

#MOTION;            'PERFORM MOTION
SP16384;            'SET THE SPEED
PR10000;            'PREPARE MODE OF MOTION
BGX;                'BEGIN MOTION
MCX
JS#CORRECT;         'MOVE TO CORRECTION
#MOTION2
SP16384;            'SET THE SPEED
PR-10000;           'PREPARE MODE OF MOTION
BGX;                'BEGIN MOTION
MCX
JS#CORRECT;         'MOVE TO CORRECTION
JP#MOTION

#CORRECT;           'CORRECTION CODE
```

```
spx=_SPX
#LOOP;              'SAVE SPEED VALUE
SP2048;             'SET A NEW SLOW CORRECTION SPEED
WT100;              'STABILIZE
JP#END,@ABS[_QSX]<10;'END CORRECTION IF ERROR IS WITHIN DEFINED
                'TOLERANCE
YRX=_QSX;           'CORRECTION MOVE
MCX
WT100;              'STABILIZE
JP#LOOP;      'KEEP CORRECTING UNTIL ERROR IS WITHIN 'TOLERANCE
#END;               'END #CORRECT SUBROUTINE, RETURNING TO CODE
SPX=spx
EN
```

Motion Smoothing

The DMC-18x2 controller allows the smoothing of the velocity profile to reduce mechanical vibrations in the system.

Trapezoidal velocity profiles have acceleration rates which change abruptly from zero to maximum value. The discontinuous acceleration results in jerk which causes vibration. The smoothing of the acceleration profile leads to a continuous acceleration profile and reduces the mechanical shock and vibration.

Using the IT and VT Commands (S curve profiling):

When operating with servo motors, motion smoothing can be accomplished with the IT and VT commands. These commands filter the acceleration and deceleration functions to produce a smooth velocity profile. The resulting velocity profile, known as S curve, has continuous acceleration and results in reduced mechanical vibrations.

The smoothing function is specified by the following commands:

IT x,y,z,w	Independent time constant
VT n	Vector time constant

The command IT is used for smoothing independent moves of the type JG, PR, PA and the command VT is used to smooth vector moves of the type VM and LM.

The smoothing parameters x,y,z,w and n are numbers between 0 and 1 and determine the degree of filtering. The maximum value of 1 implies no filtering, resulting in trapezoidal velocity profiles. Smaller values of the smoothing parameters imply heavier filtering and smoother moves.

The following example illustrates the effect of smoothing. Fig. 6.7 shows the trapezoidal velocity profile and the modified acceleration and velocity.

Note that the smoothing process results in longer motion time.

Example - Smoothing

PR 20000	Position
AC 100000	Acceleration
DC 100000	Deceleration
SP 5000	Speed
IT .5	Filter for S-curve
BG X	Begin

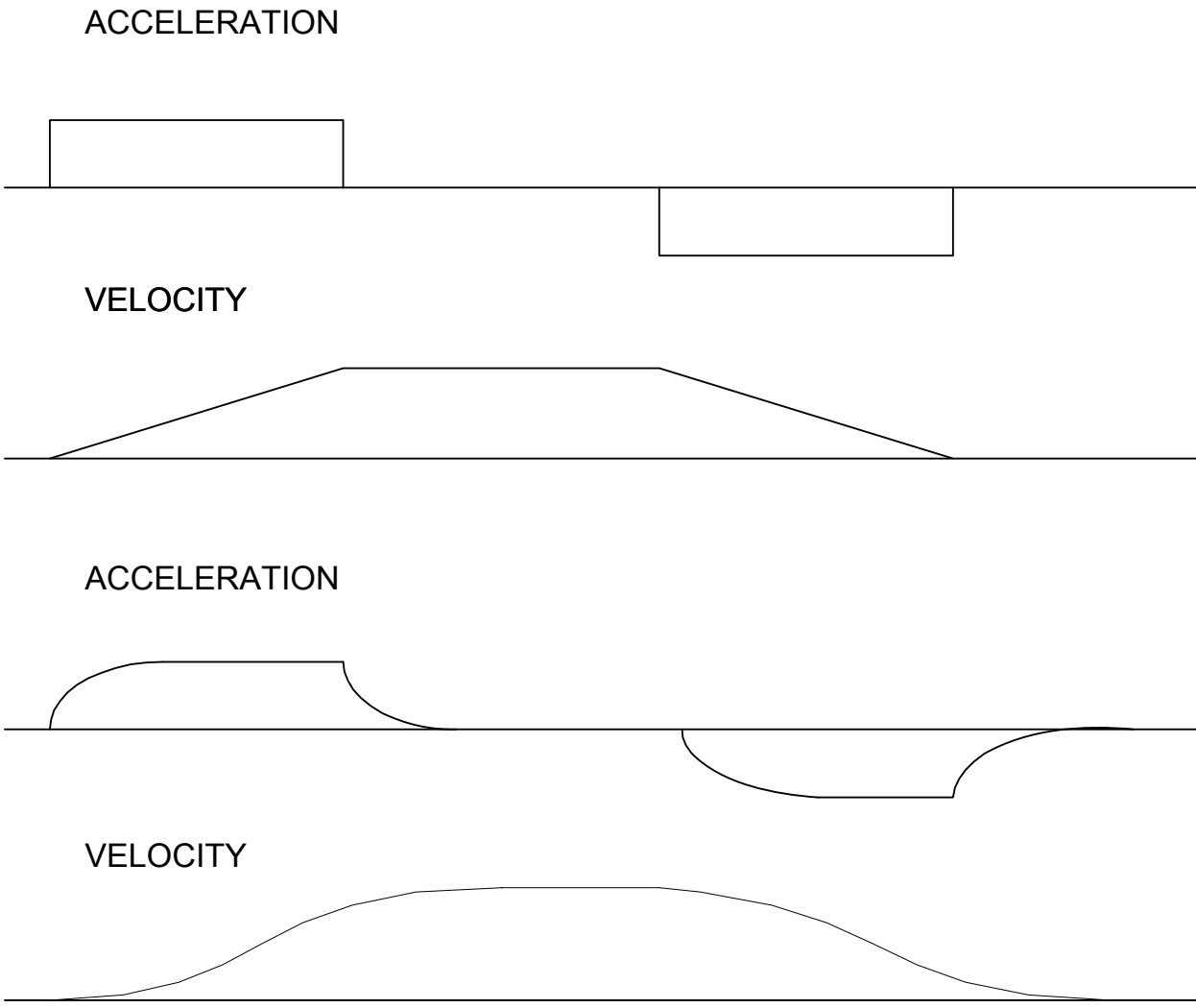


Figure 6.7 - Trapezoidal velocity and smooth velocity profiles

Using the KS Command (Step Motor Smoothing):

When operating with step motors, motion smoothing can be accomplished with the command, KS. The KS command smoothes the frequency of step motor pulses. Similar to the commands IT and VT, this produces a smooth velocity profile.

The step motor smoothing is specified by the following command:

KS x,y,z,w where x,y,z,w is an integer from 0.5 to 16 and represents the amount of smoothing

The command, IT, is used for smoothing independent moves of the type JG, PR, PA and the command, VT, is used to smooth vector moves of the type VM and LM.

The smoothing parameters, x,y,z,w and n are numbers between 0.5 and 16 and determine the degree of filtering. The minimum value of 0.5 implies no filtering, resulting in trapezoidal velocity profiles. Larger values of the smoothing parameters imply heavier filtering and smoother moves.

Note that KS is valid only for step motors.

Homing

The Find Edge (FE) and Home (HM) instructions may be used to home the motor to a mechanical reference. This reference is connected to the Home input line. The HM command initializes the motor to the encoder index pulse in addition to the Home input. The configure command (CN) is used to define the polarity of the home input.

The Find Edge (FE) instruction is useful for initializing the motor to a home switch. The home switch is connected to the Home input. When the Find Edge command and Begin are used, the motor will accelerate up to the slew speed and slew until a transition is detected on the homing line. The motor will then decelerate to a stop. A high deceleration value must be input before the find edge command is issued for the motor to decelerate rapidly after sensing the home switch. The velocity profile generated is shown in Fig. 6.8.

The Home (HM) command can be used to position the motor on the index pulse after the home switch is detected. This allows for finer positioning on initialization. The command sequence HM and BG causes the following sequence of events to occur.

1. Upon begin, the motor accelerates to the slew speed. The direction of its motion is determined by the state of the homing input. A zero (GND) will cause the motor to start in the forward direction; +5V will cause it to start in the reverse direction. The CN command is used to define the polarity of the home input.
2. Upon detecting a change in state on the home input, the motor begins decelerating to a stop.
3. The motor then traverses very slowly back until the home switch toggles again.
4. *The motor then traverses forward until the encoder index pulse is detected.
5. *The DMC-18x2 defines the home position as the position at which the index was detected and sets the encoder reading at this position to zero.

***NOTE:** For stepper motors only, the edge is found as there is no index pulse.

Example:

```
#HOME              Label
AC 1000000         Acceleration Rate
DC 1000000         Deceleration Rate
SP 5000            Speed for Home Search
HM X               Home X
BG X               Begin Motion
AM X               After Complete
MG "AT HOME"       Send Message
EN                 End
#EDGE              Label
AC 2000000         Acceleration rate
DC 2000000         Deceleration rate
```

SP 8000	Speed
FE Y	Find edge command
BG Y	Begin motion
AM Y	After complete
MG "FOUND HOME"	Send message
DP,0	Define position as 0
EN	End

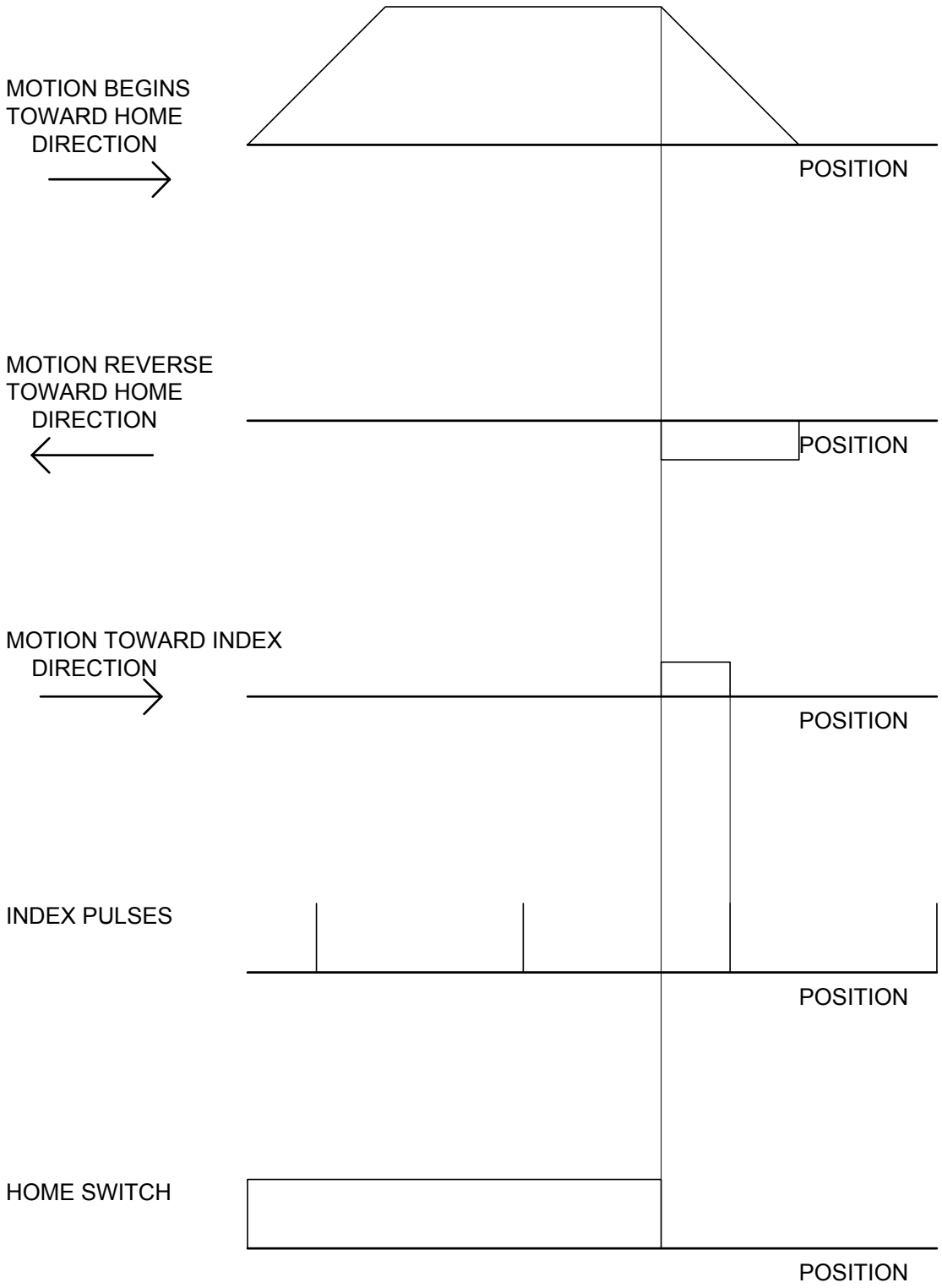


Figure 6.8 - Motion intervals in the Home sequence

High Speed Position Capture (The Latch Function)

Often it is desirable to capture the position precisely for registration applications. The DMC-18x2 provides a position latch feature. This feature allows the position of the encoder of X,Y,Z, or W to be captured upon the state change of an external input signal. The general inputs 1 through 4 correspond to each axis.

1 through 4:

IN1 X-axis latch

IN2 Y-axis latch

IN3 Z-axis latch

IN4 W-axis latch

Note: The inputs are TTL. Latch time is less than 1 μsec. (high or low going)

The DMC-18x2 software commands AL and RL are used to arm the latch and report the latched position. The steps to use the latch are as follows:

1. Give the AL XYZW command to arm the latch for the encoder.
2. Test to see if the latch has occurred (Input goes low) by using the _AL X or Y or Z or W command. Example, V1=_ALX returns the state of the X latch to the variable V1. V1 is 1 if the latch has not occurred.
3. After the latch has occurred, read the captured position with the RL XYZW command or _RLXYZW.

Note: The latch must be re-armed after each latching event.

Example:

#Latch	Latch program
JG,5000	Jog Y
BG Y	Begin motion on Y axis
AL Y	Arm Latch for Y axis
#Wait	#Wait label for loop
JP #Wait,_ALY=1	Jump to #Wait label if latch has not occurred
Result=_RLY	Set value of variable ‘Result’ equal to the report position of y axis
Result=	Print result
EN	End

Fast Update Rate Mode

The DMC-18x2 can operate with much faster servo update rates than default operation or standard operation. This mode is known as 'fast mode' and allows the controller to operate with the following update rates:

DMC-1812	125 usec
DMC-1822	125 usec
DMC-1832	250 usec
DMC-1842	250 usec

In order to run the DMC-18x2 motion controller in fast mode, fast firmware must be uploaded. This can be done through the Galil terminal software such as DMCTERM and WSDK. The fast firmware is included with the original DMC-18x2 utilities or can be found on our website.

In order to set the desired update rate, use the command TM.

When the controller is operating with the fast firmware, the following functions are disabled:

Gearing mode

Ecam mode

Pole (PL)

Stepper Motor Operation (MT 2,-2,2.5,-2.5)

Trippoints in threads 2,3, and 4

Tell Velocity (TV)

Data Record

Aux Encoders (TD)

Dual Velocity (DV)

Peak Torque Limit (TK)

Notch Filter (NB, NF, NZ)

Second Field of EI

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Chapter 7 Application Programming

Overview

The DMC-18x2 provides a powerful programming language that allows users to customize the controller for their particular application. Programs can be downloaded into the DMC-18x2 memory freeing the host computer for other tasks. However, the host computer can send commands to the controller at any time, even while a program is being executed. Only ASCII commands can be used for application programming.

In addition to standard motion commands, the DMC-18x2 provides commands that allow the DMC-18x2 to make its own decisions. These commands include conditional jumps, event triggers, and subroutines. For example, the command JP#LOOP, n<10 causes a jump to the label #LOOP if the variable n is less than 10.

For greater programming flexibility, the DMC-18x2 provides user-defined variables, arrays, and arithmetic functions. For example, with a cut-to-length operation, the length can be specified as a variable in a program which the operator can change as necessary.

The following sections in this chapter discuss all aspects of creating applications programs. The program memory size is 80 characters x 1000 lines.

Using the DMC-18x2 Editor to Enter Programs

Application programs for the DMC-18x2 may be created and edited either locally using the DMC-18x2 editor or remotely using another editor and then downloading the program into the controller. Galil's Smart Terminal and WSDK-software provide an editor and UPLOAD and DOWNLOAD utilities.

The DMC-18x2 provides a line Editor for entering and modifying programs. The Edit mode is entered with the ED instruction. (Note: The ED command can only be given when the controller is in the non-edit mode, which is signified by a colon prompt).

In the Edit Mode, each program line is automatically numbered sequentially starting with 000. If no parameter follows the ED command, the editor prompter will default to the last line of the last program in memory. If desired, the user can edit a specific line number or label by specifying a line number or label following ED.

*ED	Puts Editor at end of last program
*:ED 5	Puts Editor at line 5
*:ED #BEGIN	Puts Editor at label #BEGIN

***Note**: Another editor wiondow will not be opened in the 3-paned view of the SmartTerminal program.

NOTE: The ED command only accepts a parameter (e.g., #BEGIN) in a DOS Window. For general purposes, the editing features described in this section are not applicable when not in DOS mode.

Line numbers appear as 000,001,002, and so on. Program commands are entered following the line numbers. Multiple commands may be given on a single line as long as the total number of characters doesn't exceed 80 characters per line.

While in the Edit Mode, the programmer has access to special instructions for saving, inserting, and deleting program lines. These special instructions are listed below:

Edit Mode Commands

<RETURN>

Typing the return key causes the current line of entered instructions to be saved. The editor will automatically advance to the next line. Thus, hitting a series of <RETURN> will cause the editor to advance a series of lines. Note, changes on a program line will not be saved unless a <return> is given.

<cntrl>P

The <cntrl>P command moves the editor to the previous line.

<cntrl>I

The <cntrl>I command inserts a line above the current line. For example, if the editor is at line number 2 and <cntrl>I is applied, a new line will be inserted between lines 1 and 2. This new line will be labeled line 2. The old line number 2 is renumbered as line 3.

<cntrl>D

The <cntrl>D command deletes the line currently being edited. For example, if the editor is at line number 2 and <cntrl>D is applied, line 2 will be deleted. The previous line number 3 is now renumbered as line number 2.

<cntrl>Q

The <cntrl>Q quits the editor mode. In response, the DMC-18x2 will return a colon.

After the Edit session is over, the user may list the entered program using the LS command. If no operand follows the LS command, the entire program will be listed. The user can start listing at a specific line or label using the operand n. A command and new line number or label following the start listing operand specifies the location at which listing is to stop.

Example:

Instruction	Interpretation
:LS	List entire program
:LS 5	Begin listing at line 5
:LS 5,9	List lines 5 thru 9
:LS #A,9	List line label #A thru line 9
:LS #A, #A +5	List line label #A and additional 5 lines

Program Format

A DMC-18x2 program consists of DMC-18x2 instructions combined to solve a machine control application. Action instructions, such as starting and stopping motion, are combined with Program Flow instructions to form the complete program. Program Flow instructions evaluate real-time conditions, such as elapsed time or motion complete, and alter program flow accordingly.

Each DMC-18x2 instruction in a program must be separated by a delimiter. Valid delimiters are the semicolon (;) or carriage return. The semicolon is used to separate multiple instructions on a single

program line where the maximum number of characters on a line is 80 (including semicolons). A carriage return enters the final command on a program line.

Using Labels in Programs

All DMC-18x2 programs must begin with a label and end with an End (EN) statement. Labels start with the pound (#) sign followed by a maximum of seven characters. The first character must be a letter; after that, numbers are permitted. Spaces are not permitted.

The maximum number of labels which may be defined is 254.

Valid labels

#BEGIN

#SQUARE

#X1

#begin1

Invalid labels

#1Square

#123

A Simple Example Program:

#START	Beginning of the Program
PR 10000,20000	Specify relative distances on X and Y axes
BG XY	Begin Motion
AM	Wait for motion complete
WT 2000	Wait 2 sec
JP #START	Jump to label START
EN	End of Program

The above program moves X and Y, 10000 and 20000 units respectively. After the motion is complete, the motors rest for 2 seconds. The cycle repeats indefinitely until the stop command is issued.

Special Labels

The DMC-18x2 has special labels, which are used to define input interrupt subroutines, limit switch subroutines, error handling subroutines, and command error subroutines. The following labels listed below are the automatic subroutines supported by the controller. Sample programs for these subroutines can be found in “Automatic Subroutines for Monitoring Conditions” on page 124.

#AUTO	Starts program on power-up or reset
#ININT	Label for Input Interrupt subroutine
#LIMSWI	Label for Limit Switch subroutine
#POSERR	Label for excess Position Error subroutine
#MCTIME	Label for timeout on Motion Complete trip point
#CMDERR	Label for incorrect command subroutine
#AUTOERR	Label for checksum error

Commenting Programs

Using the command, NO

The DMC-18x2 provides a command, NO, for commenting programs. This command allows the user to include up to 78 characters on a single line after the NO command and can be used to include comments from the programmer as in the following example:

```
#PATH
NO 2-D CIRCULAR PATH
VMXY
NO VECTOR MOTION ON X AND Y
VS 10000
NO VECTOR SPEED IS 10000
VP -4000,0
NO BOTTOM LINE
CR 1500,270,-180
NO HALF CIRCLE MOTION
VP 0,3000
NO TOP LINE
CR 1500,90,-180
NO HALF CIRCLE MOTION
VE
NO END VECTOR SEQUENCE
BGS
NO BEGIN SEQUENCE MOTION
EN
NO END OF PROGRAM
```

Note: The NO command is an actual controller command. Therefore, inclusion of the NO commands will require process time by the controller.

Using REM Statements with the Galil Terminal Software.

If you are using Galil software to communicate with the DMC-18x2 controller, you may also include REM, remark, statements. 'REM' statements begin with the word 'REM' and may be followed by any comments which are on the same line. The Galil terminal software will remove these statements when the program is downloaded to the controller. For example:

```
#PATH
REM 2-D CIRCULAR PATH
VMXY
REM VECTOR MOTION ON X AND Y
VS 10000
REM VECTOR SPEED IS 10000
VP -4000,0
REM BOTTOM LINE
CR 1500,270,-180
REM HALF CIRCLE MOTION
VP 0,3000
REM TOP LINE
```

```
CR 1500,90,-180
REM HALF CIRCLE MOTION
VE
REM END VECTOR SEQUENCE
BGS
REM BEGIN SEQUENCE MOTION
EN
REM END OF PROGRAM
```

The REM statements will be removed when the program is downloaded to the controller.

Executing Programs - Multitasking

The DMC-18x2 can run up to 8 independent programs simultaneously. These programs are called threads and are numbered 0 through 7, where 0 is the main thread. Multitasking is useful for executing independent operations such as PLC functions that occur independently of motion.

The main thread differs from the others in the following ways:

1. Only the main thread, thread 0, may use the input command, IN.

2. When input interrupts are implemented for limit switches, position errors or command errors, the subroutines are executed as thread 0.

To begin execution of the various programs, use the following instruction:

```
XQ #A, n
```

Where n indicates the thread number. To halt the execution of any thread, use the instruction

```
HX n
```

where n is the thread number.

Note that both the XQ and HX commands can be performed by an executing program.

The example below produces a waveform on Output 1 independent of a move.

```
#TASK1          Task1 label
AT0             Initialize reference time
CB1             Clear Output 1
#LOOP1          Loop1 label
AT 10           Wait 10 msec from reference time
SB1             Set Output 1
AT -40          Wait 40 msec from reference time, then initialize reference
CB1             Clear Output 1
JP #LOOP1       Repeat Loop1
#TASK2          Task2 label
XQ #TASK1,1     Execute Task1
#LOOP2          Loop2 label
PR 1000         Define relative distance
BGX             Begin motion
AMX             After motion done
WT 10           Wait 10 msec
```

```
JP #LOOP2,@IN[2]=1      Repeat motion unless Input 2 is low
HX                      Halt all tasks
```

The program above is executed with the instruction XQ #TASK2,0 which designates TASK2 as the main thread (i.e. Thread 0). #TASK1 is executed within TASK2.

Debugging Programs

The DMC-18x2 provides commands and operands which are useful in debugging application programs. These commands include breakpoint, single line step through, and interrogation commands to monitor program execution, determine the state of the controller and the contents of the controllers program, array, and variable space. Operands also contain important status information which can help to debug a program.

Trace Commands

The trace command causes the controller to send each line in a program to the host computer immediately prior to execution. Tracing is enabled with the command, TR1. TR0 turns the trace function off. Note: When the trace function is enabled, the line numbers as well as the command line will be displayed as each command line is executed.

Data which is output from the controller is stored in an output FIFO buffer. The output FIFO buffer can store up to 512 characters of information. In normal operation, the controller places output into the FIFO buffer. The software on the host computer monitors this buffer and reads information as needed. When the trace mode is enabled, the controller will send information to the FIFO buffer at a very high rate. In general, the FIFO will become full since the software is unable to read the information fast enough. When the FIFO becomes full, program execution will be delayed until it is cleared. If the user wants to avoid this delay, the command CW,1 can be given. This command causes the controller to throw away the data which can not be placed into the FIFO. In this case, the controller does not delay program execution.

Error Code Command

When there is a program error, the DMC-18x2 halts the program execution at the point where the error occurs. To display the last line number of program execution, issue the command, MG _ED.

The user can obtain information about the type of error condition that occurred by using the command, TC1. This command reports back a number and a text message which describes the error condition. The command, TC0 or TC, will return the error code without the text message. For more information about the command, TC, see the Command Reference.

Stop Code Command

The status of motion for each axis can be determined by using the stop code command, SC. This can be useful when motion on an axis has stopped unexpectedly. The command SC will return a number representing the motion status. See the command reference for further information.

RAM Memory Interrogation Commands

For debugging the status of the program memory, array memory, or variable memory, the DMC-18x2 has several useful commands. The command, DM ?, will return the number of array elements currently available. The command, DA ?, will return the number of arrays which can be currently defined. For example, a standard DMC-1812 will have a maximum of 8000 array elements in up to 30 arrays. If an array of 100 elements is defined, the command DM ? will return the value 7900 and the command DA ? will return 29.

To list the contents of the variable space, use the interrogation command LV (List Variables). To list the contents of array space, use the interrogation command LA (List Arrays). To list the contents of the Program space, use the interrogation command LS (List). To list the application program labels only, use the interrogation command LL (List Labels).

Operands

In general, all operands provide information which may be useful in debugging an application program. Below is a list of operands which are particularly valuable for program debugging. To display the value of an operand, the message command may be used. For example, since the operand, _ED contains the last line of program execution, the command MG _ED will display this line number.

_ED contains the last line of program execution. Useful to determine where program stopped.

_DL contains the number of available labels.

_UL contains the number of available variables.

_DA contains the number of available arrays.

_DM contains the number of available array elements.

_AB contains the state of the Abort Input

_LFx contains the state of the forward limit switch for the 'x' axis

_LRx contains the state of the reverse limit switch for the 'x' axis

Debugging Example:

The following program has an error. It attempts to specify a relative movement while the X-axis is already in motion. When the program is executed, the controller stops at line 003. The user can then query the controller using the command, TC1. The controller responds with the corresponding explanation:

:ED	Edit Mode
000 #A	Program Label
001 PR1000	Position Relative 1000
002 BGX	Begin
003 PR5000	Position Relative 5000
004 EN	End
<cntrl> Q	Quit Edit Mode
:XQ #A	Execute #A
?003 PR5000	Error on Line 3
:TC1	Tell Error Code
?7 Command not valid while running.	Command not valid while running
:ED 3	Edit Line 3
003 AMX;PR5000;BGX	Add After Motion Command
<cntrl> Q	Quit Edit Mode
:XQ #A	Execute #A

Program Flow Commands

The DMC-18x2 provides instructions to control program flow. The DMC-18x2 program sequencer normally executes program instructions sequentially. The program flow can be altered with the use of event triggers, trippoints, and conditional jump statements.

Event Triggers & Trippoints

To function independently from the host computer, the DMC-18x2 can be programmed to make decisions based on the occurrence of an event. Such events include waiting for motion to be complete, waiting for a specified amount of time to elapse, or waiting for an input to change logic levels.

The DMC-18x2 provides several event triggers that cause the program sequencer to halt until the specified event occurs. Normally, a program is automatically executed sequentially one line at a time. When an event trigger instruction is decoded, however, the actual program sequence is halted. The program sequence does not continue until the event trigger is "tripped". For example, the motion complete trigger can be used to separate two move sequences in a program. The commands for the second move sequence will not be executed until the motion is complete on the first motion sequence. In this way, the DMC-18x2 can make decisions based on its own status or external events without intervention from a host computer.

DMC-18x2 Event Triggers

Command	Function
M X Y Z W S or T	Halts program execution until motion is complete on the specified axes or motion sequence(s). AM with no parameter tests for motion complete on all axes. This command is useful for separating motion sequences in a program.
AD X or Y or Z or W	Halts program execution until position command has reached the specified relative distance from the start of the move. Only one axis may be specified at a time.
AR X or Y or Z or W	Halts program execution until after specified distance from the last AR or AD command has elapsed. Only one axis may be specified at a time.
AP X or Y or Z or W	Halts program execution until after absolute position occurs. Only one axis may be specified at a time.
MF X or Y or Z or W	Halt program execution until after forward motion reached absolute position. Only one axis may be specified. If position is already past the point, then MF will trip immediately. Will function on geared axis or aux. inputs.
MR X or Y or Z or W	Halt program execution until after reverse motion reached absolute position. Only one axis may be specified. If position is already past the point, then MR will trip immediately. Will function on geared axis or aux. inputs.
MC X or Y or Z or W	Halt program execution until after the motion profile has been completed and the encoder has entered or passed the specified position. TW x,y,z,w sets timeout to declare an error if not in position. If timeout occurs, then the trippoint will clear and the stopcode will be set to 99. An application program will jump to label #MCTIME.
AI +/- n	Halts program execution until after specified input is at specified logic level. n specifies input line. Positive is high logic level, negative is low level. n=1 through 8 for DMC-1812, 1822, 1832, 1842.
AS X Y Z W S T	Halts program execution until specified axis has reached its slew speed.
AT +/-n	Halts program execution until n msec from reference time. AT 0 sets reference. AT n waits n msec from reference. AT -n waits n msec from reference and sets new reference after elapsed time.
AV n	Halts program execution until specified distance along a coordinated path has occurred.
WT n	Halts program execution until specified time in msec has elapsed.
BKn	Halts the program at a specific line and allows single line step through afterward.
SL	Execute the next line of the program.

Event Trigger Examples:

Event Trigger - Multiple Move Sequence

The AM trippoint is used to separate the two PR moves. If AM is not used, the controller returns a ? for the second PR command because a new PR cannot be given until motion is complete.

```
#TWOMOVE        Label
PR 2000         Position Command
BGX             Begin Motion
AMX             Wait for Motion Complete
PR 4000         Next Position Move
BGX             Begin 2nd move
EN              End program
```

Event Trigger - Set Output after Distance

Set output bit 1 after a distance of 1000 counts from the start of the move. The accuracy of the trippoint is the speed multiplied by the sample period.

```
#SETBIT         Label
SP 10000        Speed is 10000
PA 20000        Specify Absolute position
BGX             Begin motion
AD 1000         Wait until 1000 counts
SB1             Set output bit 1
EN              End program
```

Event Trigger - Repetitive Position Trigger

To set the output bit every 10000 counts during a move, the AR trippoint is used as shown in the next example.

```
#TRIP           Label
JG 50000        Specify Jog Speed
BGX;n=0         Begin Motion
#REPEAT         # Repeat Loop
AR 10000        Wait 10000 counts
TPX             Tell Position
SB1             Set output 1
WT50            Wait 50 msec
CB1             Clear output 1
n=n+1           Increment counter
JP #REPEAT,n<5  Repeat 5 times
STX             Stop
EN              End
```

Event Trigger - Start Motion on Input

This example waits for input 1 to go low and then starts motion. Note: The AI command actually halts execution of the program until the input occurs. If you do not want to halt the program sequences, you can use the Input Interrupt function (II) or use a conditional jump on an input, such as JP #GO,@IN[1] = 0.

```
#INPUT          Program Label
AI-1            Wait for input 1 low
PR 10000        Position command
BGX             Begin motion
EN              End program
```

Event Trigger - Set output when At speed

```
#ATSPEED        Program Label
JG 50000        Specify jog speed
AC 10000        Acceleration rate
BGX             Begin motion
ASX             Wait for at slew speed 50000
SB1             Set output 1
EN              End program
```

Event Trigger - Change Speed along Vector Path

The following program changes the feedrate or vector speed at the specified distance along the vector. The vector distance is measured from the start of the move or from the last AV command.

```
#VECTOR         Label
CAS             Identify coordinate system
VMXY;VS 5000    Coordinated path
VP 10000,20000  Vector position
VP 20000,30000  Vector position
VE              End vector
BGS             Begin sequence
AV 5000         After vector distance
VS 1000         Reduce speed
EN              End
```

Event Trigger - Multiple Move with Wait

This example makes multiple relative distance moves by waiting for each to be complete before executing new moves.

```
#MOVES          Label
PR 12000        Distance
SP 20000        Speed
AC 100000       Acceleration
BGX             Start Motion
AD 10000        Wait a distance of 10,000 counts
SP 5000         New Speed
AMX             Wait until motion is completed
WT 200          Wait 200 ms
PR -10000       New Position
SP 30000        New Speed
AC 150000       New Acceleration
BGX             Start Motion
```

```
EN                  End
```

Define Output Waveform Using AT

The following program causes Output 1 to be high for 10 msec and low for 40 msec. The cycle repeats every 40 msec.

```
#OUTPUT             Program label
AT0                 Initialize time reference
SB1                 Set Output 1
#LOOP               Loop
AT 10               After 10 msec from reference,
CB1                 Clear Output 1
AT –40              Wait 40 msec from reference and reset reference
SB1                 Set Output 1
JP #LOOP            Loop
EN
```

Conditional Jumps

The DMC-18x2 provides Conditional Jump (JP) and Conditional Jump to Subroutine (JS) instructions for branching to a new program location based on a specified condition. The conditional jump determines if a condition is satisfied and then branches to a new location or subroutine. Unlike event triggers, the conditional jump instruction does not halt the program sequence. Conditional jumps are useful for testing events in real-time. They allow the DMC-18x2 to make decisions without a host computer. For example, the DMC-18x2 can decide between two motion profiles based on the state of an input line.

Command Format - JP and JS

FORMAT:	DESCRIPTION
JS destination, logical condition	Jump to subroutine if logical condition is satisfied
JP destination, logical condition	Jump to location if logical condition is satisfied

The destination is a program line number or label where the program sequencer will jump if the specified condition is satisfied. Note that the line number of the first line of program memory is 0. The comma designates "IF". The logical condition tests two operands with logical operators.

Logical operators:

OPERATOR	DESCRIPTION
<	less than
>	greater than
=	equal to
<=	less than or equal to
>=	greater than or equal to
<>	not equal

Conditional Statements

The conditional statement is satisfied if it evaluates to any value other than zero. The conditional statement can be any valid DMC-18x2 numeric operand, including variables, array elements, numeric

values, functions, keywords, and arithmetic expressions. If no conditional statement is given, the jump will always occur.

Examples:

Number	V1=6
Numeric Expression	V1=V7*6
	@ABS[V1]>10
Array Element	V1<Count[2]
Variable	V1<V2
Internal Variable	_TPX=0
	_TVX>500
I/O	V1>@AN[2]
	@IN[1]=0

Multiple Conditional Statements

The DMC-18x2 will accept multiple conditions in a single jump statement. The conditional statements are combined in pairs using the operands "&" and "|". The "&" operand between any two conditions, requires that both statements must be true for the combined statement to be true. The "|" operand between any two conditions, requires that only one statement be true for the combined statement to be true. *Note: Each condition must be placed in parentheses for proper evaluation by the controller. In addition, the DMC-18x2 executes operations from left to right. For further information on Mathematical Expressions and the bit-wise operators '&' and '|', see pg. 7- 127.*

For example, using variables named V1, V2, V3 and V4:

JP #TEST, (V1<V2) & (V3<V4)

In this example, this statement will cause the program to jump to the label #TEST if V1 is less than V2 and V3 is less than V4. To illustrate this further, consider this same example with an additional condition:

JP #TEST, ((V1<V2) & (V3<V4)) | (V5<V6)

This statement will cause the program to jump to the label #TEST under two conditions: 1. If V1 is less than V2 AND V3 is less than V4. 2. If V5 is less than V6.

Using the JP Command:

If the condition for the JP command is satisfied, the controller branches to the specified label or line number and continues executing commands from this point. If the condition is not satisfied, the controller continues to execute the next commands in sequence.

Conditional	**Meaning**
JP #Loop,COUNT<10	Jump to #Loop if the variable, COUNT, is less than 10
JS #MOVE2,@IN[1]=1	Jump to subroutine #MOVE2 if input 1 is logic level high. After the subroutine MOVE2 is executed, the program sequencer returns to the main program location where the subroutine was called.
JP #BLUE,@ABS[V2]>2	Jump to #BLUE if the absolute value of variable, V2, is greater than 2
JP #C,V1*V7<=V8*V2	Jump to #C if the value of V1 times V7 is less than or equal to the value of V8*V2
JP#A	Jump to #A

Example Using JP command:

Move the X motor to absolute position 1000 counts and back to zero ten times. Wait 100 msec between moves.

```
#BEGIN              Begin Program
COUNT=10            Initialize loop counter
#LOOP               Begin loop
PA 1000             Position absolute 1000
BGX                 Begin move
AMX                 Wait for motion complete
WT 100              Wait 100 msec
PA 0                Position absolute 0
BGX                 Begin move
AMX                 Wait for motion complete
WT 100              Wait 100 msec
COUNT=COUNT-1       Decrement loop counter
JP #LOOP,COUNT>0    Test for 10 times thru loop
 EN                 End Program
```

Using If, Else, and Endif Commands

The DMC-18x2 provides a structured approach to conditional statements using IF, ELSE and ENDIF commands.

Using the IF and ENDIF Commands

An IF conditional statement is formed by the combination of an IF and ENDIF command. The IF command has as it's arguments one or more conditional statements. If the conditional statement(s) evaluates true, the command interpreter will continue executing commands which follow the IF command. If the conditional statement evaluates false, the controller will ignore commands until the associated ENDIF command is executed OR an ELSE command occurs in the program (see discussion of ELSE command below).

Note: An ENDIF command must always be executed for every IF command that has been executed. It is recommended that the user not include jump commands inside IF conditional statements since this causes re-direction of command execution. In this case, the command interpreter may not execute an ENDIF command.

Using the ELSE Command

The ELSE command is an optional part of an IF conditional statement and allows for the execution of command only when the argument of the IF command evaluates False. The ELSE command must occur after an IF command and has no arguments. If the argument of the IF command evaluates false, the controller will skip commands until the ELSE command. If the argument for the IF command evaluates true, the controller will execute the commands between the IF and ELSE command.

Nesting IF Conditional Statements

The DMC-18x2 allows for IF conditional statements to be included within other IF conditional statements. This technique is known as 'nesting' and the DMC-18x2 allows up to 255 IF conditional statements to be nested. This is a very powerful technique allowing the user to specify a variety of different cases for branching.

Command Format - IF, ELSE and ENDIF

FORMAT:	DESCRIPTION
IF conditional statement(s)	Execute commands proceeding IF command (up to ELSE command) if conditional statement(s) is true, otherwise continue executing at ENDIF command or optional ELSE command.
ELSE	Optional command. Allows for commands to be executed when argument of IF command evaluates not true. Can only be used with IF command.
ENDIF	Command to end IF conditional statement. Program must have an ENDIF command for every IF command.

Example using IF, ELSE and ENDIF:

#TEST	Begin Main Program "TEST"
II,,3	Enable input interrupts on input 1 and input 2
MG "WAITING FOR INPUT 1, INPUT 2"	Output message
#LOOP	Label to be used for endless loop
JP #LOOP	Endless loop
EN	End of main program
#ININT	Input Interrupt Subroutine
IF (@IN[1]=0)	IF conditional statement based on input 1
IF (@IN[2]=0)	2nd IF conditional statement executed if 1st IF conditional true
MG "INPUT 1 AND INPUT 2 ARE ACTIVE"	Message to be executed if 2nd IF conditional is true
ELSE	ELSE command for 2nd IF conditional statement
MG "ONLY INPUT 1 IS ACTIVE	Message to be executed if 2nd IF conditional is false
ENDIF	End of 2nd conditional statement
ELSE	ELSE command for 1st IF conditional statement
MG"ONLY INPUT 2 IS ACTIVE"	Message to be executed if 1st IF conditional statement
ENDIF	End of 1st conditional statement
#WAIT	Label to be used for a loop
JP#WAIT,(@IN[1]=0) | (@IN[2]=0)	Loop until both input 1 and input 2 are not active
RI0	End Input Interrupt Routine without restoring trippoints

Subroutines

A subroutine is a group of instructions beginning with a label and ending with an end command (EN). Subroutines are called from the main program with the jump subroutine instruction JS, followed by a label or line number, and conditional statement. Up to 8 subroutines can be nested. After the subroutine is executed, the program sequencer returns to the program location where the subroutine was called unless the subroutine stack is manipulated as described in the following section.

Example:

An example of a subroutine to draw a square 500 counts per side is given below. The square is drawn at vector position 1000,1000.

```
#M                      Begin Main Program
CB1                     Clear Output Bit 1 (pick up pen)
VP 1000,1000;VE;BGS     Define vector position; move pen
AMS                     Wait for after motion trippoint
SB1                     Set Output Bit 1 (put down pen)
JS #Square;CB1          Jump to square subroutine
EN                      End Main Program
#Square                 Square subroutine
V1=500;JS #L            Define length of side
V1=-V1;JS #L            Switch direction
EN                      End subroutine
#L;PR V1,V1;BGX         Define X,Y; Begin X
AMX;BGY;AMY             After motion on X, Begin Y
EN                      End subroutine
```

Stack Manipulation

It is possible to manipulate the subroutine stack by using the ZS command. Every time a JS instruction, interrupt or automatic routine (such as #POSERR or #LIMSWI) is executed, the subroutine stack is incremented by 1. Normally the stack is restored with an EN instruction. Occasionally it is desirable not to return back to the program line where the subroutine or interrupt was called. The ZS1 command clears 1 level of the stack. This allows the program sequencer to continue to the next line. The ZS0 command resets the stack to its initial value. For example, if a limit occurs and the #LIMSWI routine is executed, it is often desirable to restart the program sequence instead of returning to the location where the limit occurred. To do this, give a ZS command at the end of the #LIMSWI routine.

Auto-Start Routine

The DMC-18x2 has a special label for automatic program execution. A program which has been saved into the controllers non-volatile memory can be automatically executed upon power up or reset by beginning the program with the label #AUTO. The program must be saved into non-volatile memory using the command, BP. If you include the #AUTOERR routine in your program and you have a checksum error, this program will execute. For more information, read the operand section of the RS command in your command reference.

Automatic Subroutines for Monitoring Conditions

Often it is desirable to monitor certain conditions continuously without tying up the host or DMC-18x2 program sequences. The DMC-18x2 can monitor several important conditions in the background. These conditions include checking for the occurrence of a limit switch, a defined input, position error, or a command error. Automatic monitoring is enabled by inserting a special, predefined label in the applications program. The pre-defined labels are:

SUBROUTINE	DESCRIPTION
#LIMSWI	Limit switch on any axis goes low
#ININT	Input specified by II goes low

#POSERR	Position error exceeds limit specified by ER
#MCTIME	Motion Complete timeout occurred. Timeout period set by TW command
#CMDERR	Bad command given

For example, the #POSERR subroutine will automatically be executed when any axis exceeds its position error limit. The commands in the #POSERR subroutine could decode which axis is in error and take the appropriate action. In another example, the #ININT label could be used to designate an input interrupt subroutine. When the specified input occurs, the program will be executed automatically.

NOTE: An application program must be running for automatic monitoring to function.

Example - Limit Switch:

This program prints a message upon the occurrence of a limit switch. Note, for the #LIMSWI routine to function, the DMC-18x2 must be executing an applications program from memory. This can be a very simple program that does nothing but loop on a statement, such as #LOOP;JP #LOOP;EN. Motion commands, such as JG 5000 can still be sent from the PC even while the "dummy" applications program is being executed.

```
:ED                          Edit Mode
000 #LOOP                    Dummy Program
001 JP #LOOP;EN              Jump to Loop
002 #LIMSWI                  Limit Switch Label
003 MG "LIMIT OCCURRED"      Print Message
004 RE                       Return to main program
<control> Q                  Quit Edit Mode
:XQ #LOOP                    Execute Dummy Program
:JG 5000                     Jog
:BGX                         Begin Motion
```

Now, when a forward limit switch occurs on the X axis, the #LIMSWI subroutine will be executed.

Notes regarding the #LIMSWI Routine:

1) The RE command is used to return from the #LIMSWI subroutine.

2) The #LIMSWI subroutine will be re-executed if the limit switch remains active.

The #LIMSWI routine is only executed when the motor is being commanded to move.

Example - Position Error

```
:ED                              Edit Mode
000 #LOOP                        Dummy Program
001 JP #LOOP;EN                  Loop
002 #POSERR                      Position Error Routine
003 V1=_TEX                      Read Position Error
004 MG "EXCESS POSITION ERROR"   Print Message
005 MG "ERROR=",V1=              Print Error
006 RE                           Return from Error
<control> Q                      Quit Edit Mode
:XQ #LOOP                        Execute Dummy Program
:JG 100000                       Jog at High Speed
:BGX                             Begin Motion
```

Now, when excess position error occurs on the X axis, the #POSERR subroutine will be executed.

Example - Input Interrupt

#A	Label
II1	Input Interrupt on 1
JG 30000,,,60000	Jog
BGXW	Begin Motion
#LOOP;JP#LOOP;EN	Loop
#ININT	Input Interrupt
STXW;AM	Stop Motion
#TEST;JP #TEST, @IN[1]=0	Test for Input 1 still low
JG 30000,,,6000	Restore Velocities
BGXW	Begin motion
RI0	Return from interrupt routine to Main Program and do not re-enable trippoints

Example - Motion Complete Timeout

#BEGIN	Begin main program
TW 1000	Set the time out to 1000 ms
PA 10000	Position Absolute command
BGX	Begin motion
MCX	Motion Complete trip point
EN	End main program
#MCTIME	Motion Complete Subroutine
MG “X fell short”	Send out a message
EN	End subroutine

This simple program will issue the message “X fell short” if the X axis does not reach the commanded position within 1 second of the end of the profiled move.

Example - Command Error

#BEGIN	Begin main program
IN "ENTER SPEED", SPEED	Prompt for speed
JG SPEED;BGX;	Begin motion
JP #BEGIN	Repeat
EN	End main program
#CMDERR	Command error utility
JP#DONE,_ED<>2	Check if error on line 2
JP#DONE,_TC<>6	Check if out of range
MG "SPEED TOO HIGH"	Send message
MG "TRY AGAIN"	Send message
ZS1	Adjust stack
JP #BEGIN	Return to main program
#DONE	End program if other error
ZS0	Zero stack
EN	End program

The above program prompts the operator to enter a jog speed. If the operator enters a number out of range (greater than 8 million), the #CMDERR routine will be executed prompting the operator to enter a new number.

In multitasking applications, there is an alternate method for handling command errors from different threads. Using the XQ command along with the special operands described below allows the controller to either skip or retry invalid commands.

OPERAND	FUNCTION
_ED1	Returns the number of the thread that generated an error
_ED2	Retry failed command (operand contains the location of the failed command)
_ED3	Skip failed command (operand contains the location of the command after the failed command)

The operands are used with the XQ command in the following format:

XQ _ED2 (or _ED3),_ED1,1

Where the ",1" at the end of the command line indicates a restart; therefore, the existing program stack will not be removed when the above format executes.

The following example shows an error correction routine which uses the operands.

Example - Command Error w/Multitasking

```
#A                      Begin thread 0 (continuous loop)
JP#A
EN                      End of thread 0

#B                      Begin thread 1
N=-1                    Create new variable
KP N                    Set KP to value of N, an invalid value
TY                      Issue invalid command
EN                      End of thread 1

#CMDERR                 Begin command error subroutine
IF _TC=6                If error is out of range (KP -1)
N=1                     Set N to a valid number
XQ _ED2,_ED1,1          Retry KP N command
ENDIF
IF _TC=1                If error is invalid command (TY)
XQ _ED3,_ED1,1          Skip invalid command
ENDIF
EN                      End of command error routine
```

Mathematical and Functional Expressions

Mathematical Operators

For manipulation of data, the DMC-18x2 provides the use of the following mathematical operators:

OPERATOR	FUNCTION
+	Addition
-	Subtraction
*	Multiplication
/	Division
&	Logical And (Bit-wise)
|	Logical Or (On some computers, a solid vertical line appears as a broken line)
()	Parenthesis

The numeric range for addition, subtraction and multiplication operations is +/-2,147,483,647.9999. The precision for division is 1/65,000.

Mathematical operations are executed from left to right. Calculations within a parentheses have precedence.

Examples:

SPEED=7.5*V1/2	The variable, SPEED, is equal to 7.5 multiplied by V1 and divided by 2
COUNT=COUNT+2	The variable, COUNT, is equal to the current value plus 2.
RESULT=_TPX-(@COS[45]*40)	Puts the position of X - 28.28 in RESULT. 40 * cosine of 45° is 28.28
TEMP=@IN[1]&@IN[2]	TEMP is equal to 1 only if Input 1 and Input 2 are high

Bit-Wise Operators

The mathematical operators & and | are bit-wise operators. The operator, &, is a Logical And. The operator, |, is a Logical Or. These operators allow for bit-wise operations on any valid DMC-18x2 numeric operand, including variables, array elements, numeric values, functions, keywords, and arithmetic expressions. The bit-wise operators may also be used with strings. This is useful for separating characters from an input string. When using the input command for string input, the input variable will hold up to 6 characters. These characters are combined into a single value which is represented as 32 bits of integer and 16 bits of fraction. Each ASCII character is represented as one byte (8 bits), therefore the input variable can hold up to six characters. The first character of the string will be placed in the top byte of the variable and the last character will be placed in the lowest significant byte of the fraction. The characters can be individually separated by using bit-wise operations as illustrated in the following example:

#TEST	Begin main program
IN "ENTER",LEN{S6}	Input character string of up to 6 characters into variable ‘LEN’
FLEN=@FRAC[LEN]	Define variable ‘FLEN’ as fractional part of variable ‘LEN’
FLEN=$10000*FLEN	Shift FLEN by 32 bits (IE - convert fraction, FLEN, to integer)
LEN1=(FLEN&$00FF)	Mask top byte of FLEN and set this value to variable ‘LEN1’
LEN2=(FLEN&$FF00)/$100	Let variable, ‘LEN2’ = top byte of FLEN
LEN3=LEN&$000000FF	Let variable, ‘LEN3’ = bottom byte of LEN
LEN4=(LEN&$0000FF00)/$100	Let variable, ‘LEN4’ = second byte of LEN
LEN5=(LEN&$00FF0000)/$10000	Let variable, ‘LEN5’ = third byte of LEN
LEN6=(LEN&$FF000000)/$1000000	Let variable, ‘LEN6’ = fourth byte of LEN
MG LEN6 {S4}	Display ‘LEN6’ as string message of up to 4 chars
MG LEN5 {S4}	Display ‘LEN5’ as string message of up to 4 chars
MG LEN4 {S4}	Display ‘LEN4’ as string message of up to 4 chars

```
MG LEN3 {S4}        Display 'LEN3' as string message of up to 4 chars
MG LEN2 {S4}        Display 'LEN2' as string message of up to 4 chars
MG LEN1 {S4}        Display 'LEN1' as string message of up to 4 chars
EN
```

This program will accept a string input of up to 6 characters, parse each character, and then display each character. Notice also that the values used for masking are represented in hexadecimal (as denoted by the preceding '$'). For more information, see section *Sending Messages.*

To illustrate further, if the user types in the string "TESTME" at the input prompt, the controller will respond with the following:

```
T       Response from command MG LEN6 {S4}
E       Response from command MG LEN5 {S4}
S       Response from command MG LEN4 {S4}
T       Response from command MG LEN3 {S4}
M       Response from command MG LEN2 {S4}
E       Response from command MG LEN1 {S4}
```

Functions

FUNCTION	DESCRIPTION
@SIN[n]	Sine of n (n in degrees, with range of -32768 to 32767 and 16-bit fractional resolution)
@COS[n]	Cosine of n (n in degrees, with range of -32768 to 32767 and 16-bit fractional resolution)
@TAN[n]	Tangent of n (n in degrees, with range of -32768 to 32767 and 16-bit fractional resolution)
@ASIN*[n]	Arc Sine of n, between -90° and +90°. Angle resolution in 1/64000 degrees.
@ACOS* [n}	Arc Cosine of n, between 0 and 180°. Angle resolution in 1/64000 degrees.
@ATAN* [n]	Arc Tangent of n, between -90° and +90°. Angle resolution in 1/64000 degrees
@COM[n]	1's Complement of n
@ABS[n]	Absolute value of n
@FRAC[n]	Fraction portion of n
@INT[n]	Integer portion of n
@RND[n]	Round of n (Rounds up if the fractional part of n is .5 or greater)
@SQR[n]	Square root of n (Accuracy is +/-.004)
@IN[n]	Return digital input at general input n (where n starts at 1)
@OUT[n]	Return digital output at general output n (where n starts at 1)

* Note that these functions are multi-valued. An application program may be used to find the correct band.

Functions may be combined with mathematical expressions. The order of execution of mathematical expressions is from left to right and can be over-ridden by using parentheses.

Examples:

```
V1=@ABS[V7]       The variable, V1, is equal to the absolute value of variable V7.
V2=5*@SIN[POS]    The variable, V2, is equal to five times the sine of the variable, POS.
V3=@IN[1]         The variable, V3, is equal to the digital value of input 1.
```

Variables

For applications that require a parameter that is variable, the DMC-18x2 provides 254 variables. These variables can be numbers or strings. A program can be written in which certain parameters, such as position or speed, are defined as variables. The variables can later be assigned by the operator or determined by program calculations. For example, a cut-to-length application may require that a cut length be variable.

Example:

PR POSX	Assigns variable POSX to PR command
JG RPMY*70	Assigns variable RPMY multiplied by 70 to JG command.

Programmable Variables

The DMC-18x2 allows the user to create up to 254 variables. Each variable is defined by a name which can be up to eight characters. The name must start with an alphabetic character, however, numbers are permitted in the rest of the name. Spaces are not permitted. Variable names should not be the same as DMC-18x2 instructions. For example, PR is not a good choice for a variable name.

Examples of valid and invalid variable names are:

Valid Variable Names

POSX

POS1

V3OS

Invalid Variable Names

REALLONGNAME	; Cannot have more than 8 characters
123	; Cannot begin variable name with a number
SPEED Z	; Cannot have spaces in the name

Assigning Values to Variables:

Assigned values can be numbers, internal variables and keywords, functions, controller parameters and strings;

The range for numeric variable values is 4 bytes of integer (2^{31})followed by two bytes of fraction

(+/-2,147,483,647.9999).

Numeric values can be assigned to programmable variables using the equal sign.

Any valid DMC-18x2 function can be used to assign a value to a variable. For example, V1=@ABS[V2] or V2=@IN[1]. Arithmetic operations are also permitted.

To assign a string value, the string must be in quotations. String variables can contain up to six characters which must be in quotation.

Examples:

POSX=_TPX	Assigns returned value from TPX command to variable POSX.
SPEED=5.75	Assigns value 5.75 to variable SPEED
INPUT=@IN[2]	Assigns logical value of input 2 to variable INPUT
V2=V1+V3*V4	Assigns the value of V1 plus V3 times V4 to the variable V2.
VAR="CAT"	Assign the string, CAT, to VAR

Assigning Variable Values to Controller Parameters

Variable values may be assigned to controller parameters such as GN or PR.

PR V1	Assign V1 to PR command
SP P3*2000	Assign P3*2000 to SP command

Displaying the value of variables at the terminal

Variables may be sent to the screen using the format, variable=. For example, V1= , returns the value of the variable V1.

Operands

Operands allow motion or status parameters of the DMC-18x2 to be incorporated into programmable variables and expressions. Most DMC-18x2 commands have an equivalent operand - which are designated by adding an underscore (_) prior to the DMC-18x2 command. The command reference indicates which commands have an associated operand.

Status commands such as Tell Position return actual values, whereas action commands such as KP or SP return the values in the DMC-18x2 registers. The axis designation is required following the command.

Examples of Internal Variables:

POSX=_TPX	Assigns value from Tell Position X to the variable POSX.
VAR1=_KPX*2	Assigns value from KPX multiplied by two to variable, VAR1.
JP #LOOP,_TEX>5	Jump to #LOOP if the position error of X is greater than 5
JP #ERROR,_TC=1	Jump to #ERROR if the error code equals 1.

Operands can be used in an expression and assigned to a programmable variable, but they cannot be assigned a value. For example: _GNX=2 is invalid.

Special Operands (Keywords)

The DMC-18x2 provides a few additional operands which give access to internal variables that are not accessible by standard DMC-18x2 commands.

KEYWORD	FUNCTION
_BGn	*Returns a 1 if motion on axis ‘n’ is complete, otherwise returns 0.
_BN	*Returns serial # of the board.
_DA	*Returns the number of arrays available
_DL	*Returns the number of available labels for programming
_DM	*Returns the available array memory
_HMn	*Returns status of Home Switch (equals 0 or 1)
_LFn	Returns status of Forward Limit switch input of axis ‘n’ (equals 0 or 1)
_LRX	Returns status of Reverse Limit switch input of axis ‘n’ (equals 0 or 1)
_UL	*Returns the number of available variables
TIME	Free-Running Real Time Clock (off by 2.4% - Resets with power-on). Note: TIME does not use an underscore character (_) as other keywords.

* - These keywords have corresponding commands while the keywords _LF, _LR, and TIME do not have any associated commands. All keywords are listed in the Command Reference manual.

Examples of Keywords:

V1=_LFX	Assign V1 the logical state of the Forward Limit Switch on the X-axis
V3=TIME	Assign V3 the current value of the time clock
V4=_HMW	Assign V4 the logical state of the Home input on the W-axis

Arrays

For storing and collecting numerical data, the DMC-18x2 provides array space for 8000 elements. The arrays are one dimensional and up to 30 different arrays may be defined. Each array element has a numeric range of 4 bytes of integer (2^{31})followed by two bytes of fraction (+/-2,147,483,647.9999).

Arrays can be used to capture real-time data, such as position, torque and analog input values. In the contouring mode, arrays are convenient for holding the points of a position trajectory in a record and playback application.

Defining Arrays

An array is defined with the command DM. The user must specify a name and the number of entries to be held in the array. An array name can contain up to eight characters, starting with an uppercase alphabetic character. The number of entries in the defined array is enclosed in [ ].

Example:

DM POSX[7]	Defines an array names POSX with seven entries
DM SPEED[100]	Defines an array named speed with 100 entries
DM POSX[0]	Frees array space

Assignment of Array Entries

Like variables, each array element can be assigned a value. Assigned values can be numbers or returned values from instructions, functions and keywords.

Array elements are addressed starting at count 0. For example the first element in the POSX array (defined with the DM command, DM POSX[7]) would be specified as POSX[0].

Values are assigned to array entries using the equal sign. Assignments are made one element at a time by specifying the element number with the associated array name.

NOTE: Arrays must be defined using the command, DM, before assigning entry values.

Examples:

DM SPEED[10]	Dimension Speed Array
SPEED[1]=7650.2	Assigns the second element of the array, SPEED the value 7650.2
SPEED[1]=	Returns array element value
POSX[10]=_TPX	Assigns the 11th element of the array POSX the returned value from the tell position command.
CON[2]=@COS[POS]*2	Assigns the third element of the array CON the cosine of the variable POS multiplied by 2.
TIMER[1]=TIME	Assigns the second element of the array timer the returned value of the TIME keyword.

Using a Variable to Address Array Elements

An array element number can also be a variable. This allows array entries to be assigned sequentially using a counter.

For example:

#A	Begin Program
COUNT=0;DM POS[10]	Initialize counter and define array
#LOOP	Begin loop
WT 10	Wait 10 msec
POS[COUNT]=_TPX	Record position into array element
POS[COUNT]=	Report position
COUNT=COUNT+1	Increment counter
JP #LOOP,COUNT<10	Loop until 10 elements have been stored
EN	End Program

The above example records 10 position values at a rate of one value per 10 msec. The values are stored in an array named POS. The variable, COUNT, is used to increment the array element counter. The above example can also be executed with the automatic data capture feature described below.

Uploading and Downloading Arrays to On Board Memory

Arrays may be uploaded and downloaded using the QU and QD commands.

QU array[],start,end,delim

QD array[],start,end

Where array is an array name such as A[].

Start is the first element of array (default=0)

End is the last element of array (default=last element)

Delim specifies whether the array data is separated by a comma (delim=1) or a carriage return (delim=0).

The file is terminated using <control>Z, <control>Q, <control>D or \.

Automatic Data Capture into Arrays

The DMC-18x2 provides a special feature for automatic capture of data such as position, position error, inputs or torque. This is useful for teaching motion trajectories or observing system performance. Up to four types of data can be captured and stored in four arrays. The capture rate or time interval may be specified. Recording can done as a one time event or as a circular continuous recording.

Command Summary - Automatic Data Capture

COMMAND	DESCRIPTION
RA n[],m[],o[],p[]	Selects up to four arrays for data capture. The arrays must be defined with the DM command.
RD type1,type2,type3,type4	Selects the type of data to be recorded, where type1, type2, type3, and type 4 represent the various types of data (see table below). The order of data type is important and corresponds with the order of n,m,o,p arrays in the RA command.
RC n,m	The RC command begins data collection. Sets data capture time interval where n is an integer between 1 and 8 and designates 2^n msec between data. m is optional and specifies the number of elements to be captured. If m is not defined, the number of elements defaults to the smallest array defined by DM. When m is a negative number, the recording is done continuously in a circular manner. _RD is the recording pointer and indicates the address of the next array element. n=0 stops recording.
RC?	Returns a 0 or 1 where, 0 denotes not recording, 1 specifies recording in progress

Data Types for Recording:

DATA TYPE	DESCRIPTION
_DEX	2nd encoder position (dual encoder)
_TPX	Encoder position
_TEX	Position error
_RPX	Commanded position
_RLX	Latched position
_TI	Inputs
_OP	Output
_TSX	Switches (only bit 0-4 valid)
_SCX	Stop code
_NOX	Status bits
_TTX	Torque (reports digital value +/-8097)

Note: X may be replaced by Y,Z or W for capturing data on other axes.

Operand Summary - Automatic Data Capture

_RC	Returns a 0 or 1 where, 0 denotes not recording, 1 specifies recording in progress
_RD	Returns address of next array element.

Example - Recording into An Array

During a position move, store the X and Y positions and position error every 2 msec.

```
#RECORD                          Begin program
DM XPOS[300],YPOS[300]           Define X,Y position arrays
DM XERR[300],YERR[300]           Define X,Y error arrays
RA XPOS[],XERR[],YPOS[],YERR[]   Select arrays for capture
RD _TPX,_TEX,_TPY,_TEY           Select data types
PR 10000,20000                   Specify move distance
RC1                              Start recording now, at rate of 2 msec
BG XY                            Begin motion
#A;JP #A,RC=1                    Loop until done
MG "DONE"                        Print message
EN                               End program
#PLAY                            Play back
N=0                              Initial Counter
JP# DONE,N>300                   Exit if done
N=                               Print Counter
X POS[N]=                        Print X position
Y POS[N]=                        Print Y position
XERR[N]=                         Print X error
YERR[N]=                         Print Y error
N=N+1                            Increment Counter
#DONE                            Done
EN                               End Program
```

Deallocating Array Space

Array space may be deallocated using the DA command followed by the array name. DA*[0] deallocates all the arrays.

Input of Data (Numeric and String)

Input of Data

The command, IN, is used to prompt the user to input numeric or string data. Using the IN command, the user may specify a message prompt by placing a message in quotations. When the controller executes an IN command, the controller will wait for the input of data. The input data is assigned to the specified variable or array element.

An Example for Inputting Numeric Data

```
#A
IN "Enter Length",LENX
EN
```

In this example, the message “Enter Length” is displayed on the computer screen. The controller waits for the operator to enter a value. The operator enters the numeric value which is assigned to the variable, LENX.

Cut-to-Length Example

In this example, a length of material is to be advanced a specified distance. When the motion is complete, a cutting head is activated to cut the material. The length is variable, and the operator is prompted to input it in inches. Motion starts with a start button which is connected to input 1.

The load is coupled with a 2 pitch lead screw. A 2000 count/rev encoder is on the motor, resulting in a resolution of 4000 counts/inch. The program below uses the variable LEN, to length. The IN command is used to prompt the operator to enter the length, and the entered value is assigned to the variable LEN.

```
#BEGIN                  LABEL
AC 800000               Acceleration
DC 800000               Deceleration
SP 5000                 Speed
LEN=3.4                 Initial length in inches
#CUT                    Cut routine
AI1                     Wait for start signal
IN "enter Length(IN)",LEN  Prompt operator for length in inches
PR LEN *4000            Specify position in counts
BGX                     Begin motion to move material
AMX                     Wait for motion done
SB1                     Set output to cut
WT100;CB1               Wait 100 msec, then turn off cutter
JP #CUT                 Repeat process
EN                      End program
```

Inputting String Variables

String variables with up to six characters may input using the specifier, {Sn} where n represents the number of string characters to be input. If n is not specified, six characters will be accepted. For example, IN "Enter X,Y or Z",V{S} specifies a string variable to be input.

Output of Data (Numeric and String)

Numerical and string data can be output from the controller using several methods. The message command, MG, can output string and numerical data. Also, the controller can be commanded to return the values of variables and arrays, as well as other information using the interrogation commands (the interrogation commands are described in chapter 5).

Sending Messages

Messages may be sent to the bus using the message command, MG. This command sends specified text and numerical or string data from variables or arrays to the screen.

Text strings are specified in quotes and variable or array data is designated by the name of the variable or array. For example:

```
MG "The Final Value is", RESULT
```

In addition to variables, functions and commands, responses can be used in the message command. For example:

```
MG "The input is", @IN[1]
MG "The Position of X is", _TPX
```

Formatting Messages

String variables can be formatted using the specifier, {Sn} where n is the number of characters, 1 thru 6. For example:

```
MG STR {S3}
```

This statement returns 3 characters of the string variable named STR.

Numeric data may be formatted using the {Fn.m} expression following the completed MG statement. {$n.m} formats data in HEX instead of decimal. The actual numerical value will be formatted with n characters to the left of the decimal and m characters to the right of the decimal. Leading zeros will be used to display specified format.

For example::

```
MG "The Final Value is", RESULT {F5.2}
```

If the value of the variable RESULT is equal to 4.1, this statement returns the following:

```
The Final Value is 00004.10
```

If the value of the variable RESULT is equal to 999999.999, the above message statement returns the following:

```
The Final Value is 99999.99
```

The message command normally sends a carriage return and line feed following the statement. The carriage return and the line feed may be suppressed by sending {N} at the end of the statement. This is useful when a text string needs to surround a numeric value.

Example:

```
#A
```

```
JG 50000;BGX;ASX
MG "The Speed is", _TVX {F5.1} {N}
MG "counts/sec"
EN
```

When #A is executed, the above example will appear on the screen as:

```
The speed is 50000 counts/sec
```

Using the MG Command to Configure Terminals

The MG command can be used to configure a terminal. Any ASCII character can be sent by using the format {^n} where n is any integer between 1 and 255.

Example:

```
MG {^07} {^255}
```

sends the ASCII characters represented by 7 and 255 to the bus.

Summary of Message Functions:

FUNCTION	DESCRIPTION
" "	Surrounds text string
{Fn.m}	Formats numeric values in decimal n digits to the right of the decimal point and m digits to the left
{$n.m}	Formats numeric values in hexadecimal
{^n}	Sends ASCII character specified by integer n
{N}	Suppresses carriage return/line feed
{Sn}	Sends the first n characters of a string variable, where n is 1 thru 6.

Displaying Variables and Arrays

Variables and arrays may be sent to the screen using the format, variable= **or** array[x]=. For example, V1= , returns the value of V1.

Example - Printing a Variable and an Array element

```
#DISPLAY            Label
DM POSX[7]          Define Array POSX with 7 entries
PR 1000             Position Command
BGX                 Begin
AMX                 After Motion
V1=_TPX             Assign Variable V1
POSX[1]=_TPX        Assign the first entry
V1=                 Print V1
```

Interrogation Commands

The DMC-18x2 has a set of commands that directly interrogate the controller. When these commands are entered, the requested data is returned in decimal format on the next line followed by a carriage return and line feed. The format of the returned data can be changed using the Position Format (PF), and Leading Zeros (LZ) command. For a complete description of interrogation commands, see chapter 5.

Using the PF Command to Format Response from Interrogation Commands

The command, PF, can change format of the values returned by theses interrogation commands:

BL ?	LE ?
DE ?	PA ?
DP ?	PR ?
EM ?	TN ?
FL ?	VE ?
IP ?	TE
TP	

The numeric values may be formatted in decimal or hexadecimal with a specified number of digits to the right and left of the decimal point using the PF command.

Position Format is specified by:

PF m.n

where m is the number of digits to the left of the decimal point (0 thru 10) and n is the number of digits to the right of the decimal point (0 thru 4) A negative sign for m specifies hexadecimal format.

Hex values are returned preceded by a $ and in 2's complement. Hex values should be input as signed 2's complement, where negative numbers have a negative sign. The default format is PF 10.0.

If the number of decimal places specified by PF is less than the actual value, a nine appears in all the decimal places.

Examples:

:DP21	Define position
:TPX	Tell position
0000000021	Default format
:PF4	Change format to 4 places
:TPX	Tell position
0021	New format
:PF-4	Change to hexadecimal format
:TPX	Tell Position
$0015	Hexadecimal value
:PF2	Format 2 places
:TPX	Tell Position
99	Returns 99 if position greater than 99

Removing Leading Zeros from Response to Interrogation Response

The leading zeros on data returned as a response to interrogation commands can be removed by the use of the command, LZ.

Example - Using the LZ command

LZ0	Disables the LZ function
TP	Tell Position Interrogation Command
-0000000009, 0000000005, 0000000000, 0000000007	Response from Interrogation Command (With Leading Zeros)
LZ1	Enables the LZ function
TP	Tell Position Interrogation Command
-9, 5, 0, 7	Response from Interrogation Command (Without Leading Zeros)

Local Formatting of Response of Interrogation Commands

The response of interrogation commands may be formatted locally. To format locally, use the command, {Fn.m} or {$n.m} on the same line as the interrogation command. The symbol F specifies that the response should be returned in decimal format and $ specifies hexadecimal. n is the number of digits to the left of the decimal, and m is the number of digits to the right of the decimal. For example:

Examples:

TP {F2.2}	Tell Position in decimal format 2.2
-05.00, 05.00, 00.00, 07.00	Response from Interrogation Command
TP {$4.2}	Tell Position in hexadecimal format 4.2
FFFB.00,$0005.00,$0000.00,$0007.00	Response from Interrogation Command

Formatting Variables and Array Elements

The Variable Format (VF) command is used to format variables and array elements. The VF command is specified by:

VF m.n

where m is the number of digits to the left of the decimal point (0 thru 10) and n is the number of digits to the right of the decimal point (0 thru 4).

A negative sign for m specifies hexadecimal format. The default format for VF is VF 10.4

Hex values are returned preceded by a $ and in 2's complement.

:V1=10	Assign V1
:V1=	Return V1
0000000010.0000	Default format
:VF2.2	Change format
:V1=	Return V1
10.00	New format
:VF-2.2	Specify hex format
:V1=	Return V1
$0A.00	Hex value
:VF1	Change format
:V1=	Return V1
9	Overflow

Local Formatting of Variables

PF and VF commands are global format commands that effect the format of all relevant returned values and variables. Variables may also be formatted locally. To format locally, use the command, {Fn.m} or {$n.m} following the variable name and the '=' symbol. F specifies decimal and $ specifies hexadecimal. n is the number of digits to the left of the decimal, and m is the number of digits to the right of the decimal. For example:

Examples:

:V1=10	Assign V1
:V1=	Return V1
0000000010.0000	Default Format
:V1={F4.2}	Specify local format
0010.00	New format
:V1={$4.2}	Specify hex format
$000A.00	Hex value
:V1="ALPHA"	Assign string "ALPHA" to V1
:V1={S4}	Specify string format first 4 characters
ALPH	

The local format is also used with the MG command.

Fast Firmware Mode

To allow faster servo update rates, a minimized firmware mode is available where certain features are disabled. When the fast firmware mode is activated the following functions are NOT available:

Gearing

CAM

PL

Stepper Mode

Trippoints in the main thread

DMA

TV

DATARECORD

The minimum sample times (TM) in the fast mode are as follows

	FAST MODE	NORMAL MODE
DMC-1812, 1822	125 μsec	250 μsec
DMC-1832, 1842	250 μsec	375 μsec

The FAST MODE firmware is available as part of the utilities disks shipped with the DMC-18x2. The FAST MODE firmware must be downloaded into the DMC-18x2. Run a terminal program (through WSDK, DMCWIN, DMCDOS, etc.) and select update controller firmare from the options menu.

Converting to User Units

Variables and arithmetic operations make it easy to input data in desired user units such as inches or RPM.

The DMC-18x2 position parameters such as PR, PA and VP have units of quadrature counts. Speed parameters such as SP, JG and VS have units of counts/sec. Acceleration parameters such as AC, DC, VA and VD have units of counts/sec^2. The controller interprets time in milliseconds.

All input parameters must be converted into these units. For example, an operator can be prompted to input a number in revolutions. A program could be used such that the input number is converted into counts by multiplying it by the number of counts/revolution.

Example:

#RUN	Label
IN "ENTER # OF REVOLUTIONS",N1	Prompt for revs
PR N1*2000	Convert to counts
IN "ENTER SPEED IN RPM",S1	Prompt for RPMs
SP S1*2000/60	Convert to counts/sec
IN "ENTER ACCEL IN RAD/SEC2",A1	Prompt for ACCEL
AC A1*2000/(2*3.14)	Convert to counts/sec2
BG	Begin motion
EN	End program

Programmable Hardware I/O

Digital Outputs

The DMC-18x2 has an 8-bit uncommitted output port for controlling external events.

For example:

Instruction	Function
SB6	Sets bit 6 of output port
CB4	Clears bit 4 of output port

The Output Bit (OB) instruction is useful for setting or clearing outputs depending on the value of a variable, array, input or expression. Any non-zero value results in a set bit.

Instruction	Function
OB1, POS	Set Output 1 if the variable POS is non-zero. Clear Output 1 if POS equals 0.
OB 2, @IN [1]	Set Output 2 if Input 1 is high. If Input 1 is low, clear Output 2.
OB 3, @IN [1]&@IN [2]	Set Output 3 only if Input 1 and Input 2 are high.
OB 4, COUNT [1]	Set Output 4 if element 1 in the array COUNT is non-zero.

The output port can be set by specifying an 8-bit word using the instruction OP (Output Port). This instruction allows a single command to define the state of the entire 8-bit output port, where 2^0 is output 1, 2^1 is output 2 and so on. A 1 designates that the output is on.

For example:

Instruction	Function
OP6	Sets outputs 2 and 3 of output port to high. All other bits are 0. ($2^1 + 2^2 = 6$)
OP0	Clears all bits of output port to zero
OP 255	Sets all bits of output port to one. ($2^0 + 2^1 + 2^2 + 2^3 + 2^4 + 2^5 + 2^6 + 2^7$)

The output port is useful for setting relays or controlling external switches and events during a motion sequence.

Example - Turn on output after move

#OUTPUT	Label
PR 2000	Position Command
BG	Begin
AM	After move
SB1	Set Output 1
WT 1000	Wait 1000 msec
CB1	Clear Output 1
EN	End

Digital Inputs

The DMC-18x2 has eight digital inputs for controlling motion by local switches. The @IN[n] function returns the logic level of the specified input 1 through 8.

For example, a Jump on Condition instruction can be used to execute a sequence if a high condition is noted on an input 3. To halt program execution, the After Input (AI) instruction waits until the specified input has occurred.

Example:

JP #A,@IN[1]=0	Jump to A if input 1 is low
JP #B,@IN[2]=1	Jump to B if input 2 is high
AI 7	Wait until input 7 is high
AI -6	Wait until input 6 is low

Example - Start Motion on Switch

Motor X must turn at 4000 counts/sec when the user flips a panel switch to on. When panel switch is turned to off position, motor X must stop turning.

Solution: Connect panel switch to input 1 of DMC-18x2. High on input 1 means switch is in on position.

Instruction	Function
#S;JG 4000	Set speed
AI 1;BGX	Begin after input 1 goes high
AI -1;STX	Stop after input 1 goes low
AMX;JP #S	After motion, repeat
EN;	

Input Interrupt Function

The DMC-18x2 provides an input interrupt function which causes the program to automatically execute the instructions following the #ININT label. This function is enabled using the II m,n,o command. The m specifies the beginning input and n specifies the final input in the range. The parameter o is an interrupt mask. If m and n are unused, o contains a number with the mask. A 1 designates that input to be enabled for an interrupt, where 2^0 is bit 1, 2^1 is bit 2 and so on. For example, II,,5 enables inputs 1 and 3 ($2^0 + 2^2 = 5$).

A low input on any of the specified inputs will cause automatic execution of the #ININT subroutine. The Return from Interrupt (RI) command is used to return from this subroutine to the place in the program where the interrupt had occurred. If it is desired to return to somewhere else in the program after the execution of the #ININT subroutine, the Zero Stack (ZS) command is used followed by unconditional jump statements.

IMPORTANT: Use the RI instruction (not EN) to return from the #ININT subroutine.

Examples - Input Interrupt

#A	Label #A
II 1	Enable input 1 for interrupt function
JG 30000,-20000	Set speeds on X and Y axes
BG XY	Begin motion on X and Y axes
#B	Label #B
TP XY	Report X and Y axes positions
WT 1000	Wait 1000 milliseconds
JP #B	Jump to #B
EN	End of program
#ININT	Interrupt subroutine
MG "Interrupt has occurred"	Displays the message
ST XY	Stops motion on X and Y axes
#LOOP;JP #LOOP,@IN[1]=0	Loop until Interrupt cleared
JG 15000,10000	Specify new speeds
WT 300	Wait 300 milliseconds
BG XY	Begin motion on X and Y axes
RI	Return from Interrupt subroutine

Example Applications

Wire Cutter

An operator activates a start switch. This causes a motor to advance the wire a distance of 10". When the motion stops, the controller generates an output signal which activates the cutter. Allowing 100 ms for the cutting completes the cycle.

Suppose that the motor drives the wire by a roller with a 2" diameter. Also assume that the encoder resolution is 1000 lines per revolution. Since the circumference of the roller equals 2π inches, and it corresponds to 4000 quadrature, one inch of travel equals:

$$4000/2\pi = 637 \text{ count/inch}$$

This implies that a distance of 10 inches equals 6370 counts, and a slew speed of 5 inches per second, for example, equals 3185 count/sec.

The input signal may be applied to input 1, for example, and the output signal is chosen as output 1. The motor velocity profile and the related input and output signals are shown in Fig. 7.1.

The program starts at a state that we define as #A. Here the controller waits for the input pulse on I1. As soon as the pulse is given, the controller starts the forward motion.

Upon completion of the forward move, the controller outputs a pulse for 20 ms and then waits an additional 80 ms before returning to #A for a new cycle.

Instruction	Function
#A	Label
AI1	Wait for input 1
PR 6370	Distance
SP 3185	Speed
BGX	Start Motion
AMX	After motion is complete
SB1	Set output bit 1
WT 20	Wait 20 ms
CB1	Clear output bit 1
WT 80	Wait 80 ms
JP #A	Repeat the process

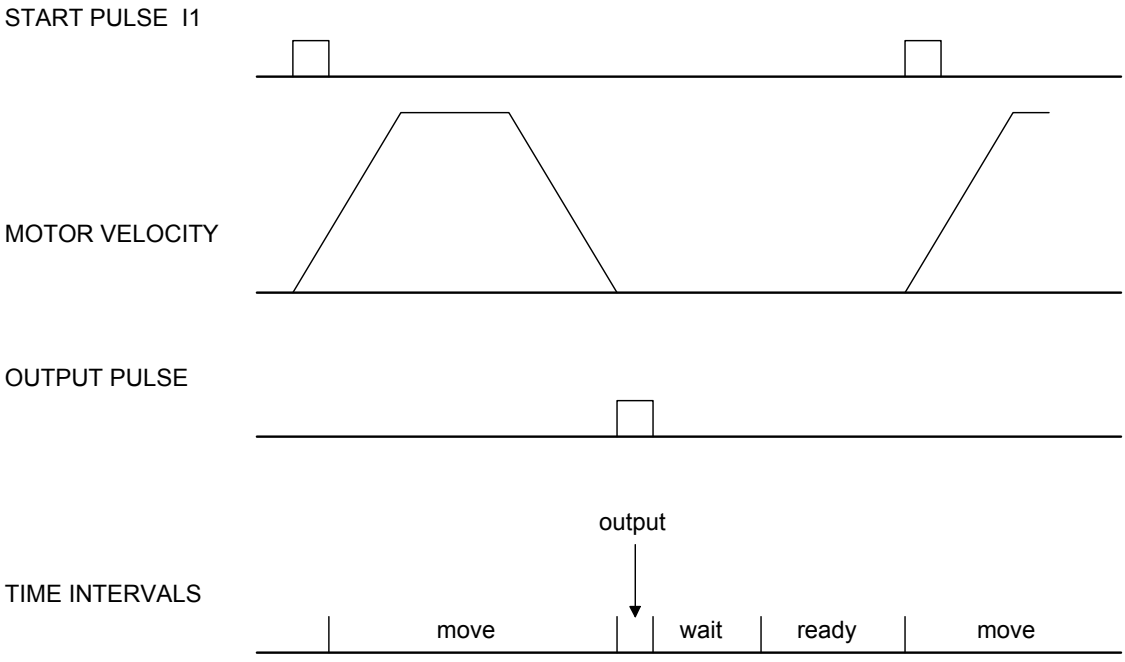

Figure 7.1 - Motor Velocity and the Associated Input/Output signals

X-Y Table Controller

An X-Y-Z system must cut the pattern shown in Fig. 7.2. The X-Y table moves the plate while the Z-axis raises and lowers the cutting tool.

The heavy solid curves in Fig. 7.2 indicate sections where cutting takes place. Those must be performed at a feedrate of 1 inch per second. The light lines correspond to non-cutting moves and should be performed at 5 inch per second. The acceleration rate is 0.1 g.

The motion starts at point A, with the Z-axis raised. An X-Y motion to point B is followed by lowering the Z-axis and performing a cut along the circle. Once the circular motion is completed, the Z-axis is raised and the motion continues to point C, etc.

Assume that all of the 3 axes are driven by lead screws with 10 turns-per-inch pitch. Also assume encoder resolution of 1000 lines per revolution. This results in the relationship:

1 inch = 40,000 counts

and the speeds of

1 in/sec = 40,000 count/sec

5 in/sec = 200,000 count/sec

an acceleration rate of 0.1g equals

$0.1g = 38.6$ in/s2 = 1,544,000 count/s^2

Note that the circular path has a radius of 2" or 80000 counts, and the motion starts at the angle of 270° and traverses 360° in the CW (negative direction). Such a path is specified with the instruction

CR 80000,270,-360

Further assume that the Z must move 2" at a linear speed of 2" per second. The required motion is performed by the following instructions:

Instruction	Function
#A	Label
VM XY	Circular interpolation for XY
VP 160000,160000	Positions
VE	End Vector Motion
VS 200000	Vector Speed
VA 1544000	Vector Acceleration
BGS	Start Motion
AMS	When motion is complete
PR,,-80000	Move Z down
SP,,80000	Z speed
BGZ	Start Z motion
AMZ	Wait for completion of Z motion
CR 80000,270,-360	Circle
VE	
VS 40000	Feedrate
BGS	Start circular move
AMS	Wait for completion
PR,,80000	Move Z up
BGZ	Start Z move
AMZ	Wait for Z completion
PR -21600	Move X

```
SP 20000            Speed X
BGX                 Start X
AMX                 Wait for X completion
PR,,-80000          Lower Z
BGZ
AMZ
CR 80000,270,-360   Z second circle move
VE
VS 40000
BGS
AMS
PR,,80000           Raise Z
BGZ
AMZ
VP -37600,-16000    Return XY to start
VE
VS 200000
BGS
AMS
EN
```

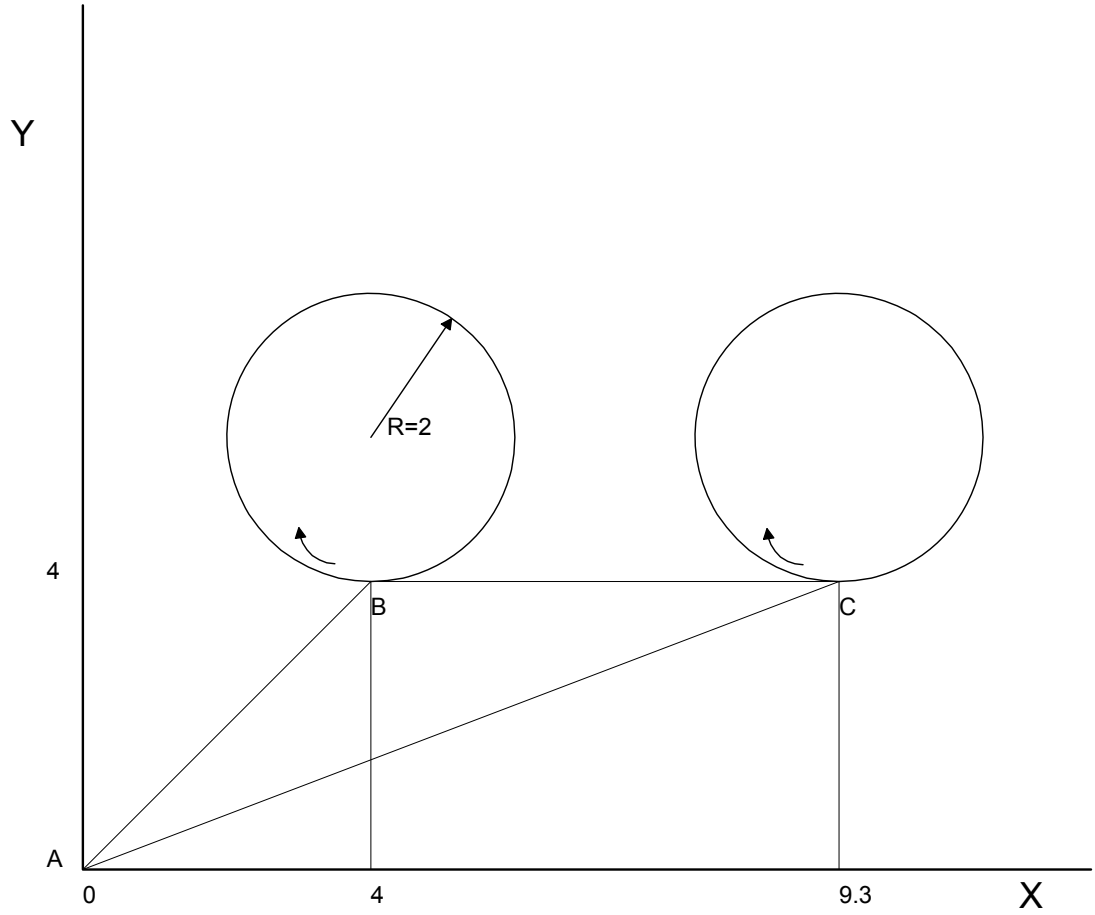

Figure 7.2 - Motor Velocity and the Associated Input/Output signals

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Chapter 8 Hardware & Software Protection

Introduction

The DMC-18x2 provides several hardware and software features to check for error conditions and to inhibit the motor on error. These features help protect the system components from damage.

WARNING: Machinery in motion can be dangerous! It is the responsibility of the user to design effective error handling and safety protection as part of the machine. Since the DMC-18x2 is an integral part of the machine, the engineer should design his overall system with protection against a possible component failure on the DMC-18x2. Galil shall not be liable or responsible for any incidental or consequential damages.

Hardware Protection

The DMC-18x2 includes hardware input and output protection lines for error and mechanical limit conditions. These include:

Output Protection Lines

Amp Enable - This signal goes low when the motor off command is given, when the position error exceeds the value specified by the Error Limit (ER) command, or when an off-on-error condition is enabled (OE1) and the abort command is given. Each axis amplifier has a separate enable line. This signal also goes low when the watch-dog timer is activated. *Note: The standard configuration of the AEN signal is TTL active low. Both the polarity and the amplitude can be changed if you are using the ICM-1900 interface board. To make these changes, see section entitled 'Amplifier Interface' in Chapter 3.*

Error Output - The error output is a TTL signal which indicates an error condition in the controller. This signal is available on the interconnect module as ERROR. When the error signal is low, this indicates one of the following error conditions:

1. At least one axis has a position error greater than the error limit. The error limit is set by using the command ER.
2. The reset line on the controller is held low or is being affected by noise.
3. There is a failure on the controller and the processor is resetting itself.
4. There is a failure with the output IC which drives the error signal.

Input Protection Lines

Abort - A low input stops commanded motion instantly without a controlled deceleration. For any axis in which the Off-On-Error function is enabled, the amplifiers will be disabled. This could cause the motor to 'coast' to a stop. If the Off-On-Error function is not enabled, the motor will instantaneously stop and servo at the current position. The Off-On-Error function is further discussed in this chapter.

Selective Abort – The controller can be configured to provide an individual abort for each axis. Activation of the selective abort signal will act the same as the Abort Input but only on the specific axis. To configure the controller for selective abort, issue the command CN,,,1. This configures the inputs 5,6,7,8 to act as selective aborts for axes A,B, C, D respectively.

Forward Limit Switch - Low input inhibits motion in forward direction. (The CN command can be used to change the polarity of the limit switches.) If the motor is moving in the forward direction when the limit switch is activated, the motion will decelerate and stop. In addition, if the motor is moving in the forward direction, the controller will automatically jump to the limit switch subroutine, #LIMSWI (if such a routine has been written by the user).

Reverse Limit Switch - Low input inhibits motion in reverse direction. (The CN command can be used to change the polarity of the limit switches.) If the motor is moving in the reverse direction when the limit switch is activated, the motion will decelerate and stop. In addition, if the motor is moving in the reverse direction, the controller will automatically jump to the limit switch subroutine, #LIMSWI (if such a routine has been written by the user).

Software Protection

The DMC-18x2 provides a programmable error limit. The error limit refers to a difference in the actual and commanded position of the motor. This limit can be set for any number between 1 and 32767 using the ER n command. The default value for ER is 16384.

Example:

ER 200,300,400,500	Set X-axis error limit for 200, Y-axis error limit to 300, Z-axis error limit to 400 counts, W-axis error limit to 500 counts
ER,1,,10	Set Y-axis error limit to 1 count, set W-axis error limit to 10 counts.

The units of the error limit are quadrature counts. The error is the difference between the command position and actual encoder position. If the absolute value of the error exceeds the value specified by ER, the DMC-18x2 will generate signals to warn the host system of the error condition. These signals include:

Signal or Function	State if Error Occurs
# POSERR	Jumps to automatic excess position error subroutine (if included in program)
Error Light	Turns on
OE Function	Shuts motor off if OE1
AEN Output Line	Goes low

The Jump if Condition statement is useful for branching within the program due to an error. The position error of X,Y,Z, and W can be monitored during execution using the TE command.

Programmable Position Limits

The DMC-18x2 provides programmable forward and reverse position limits. These are set by the BL (Backwards Limit) and FL (Forward Limit) software commands. Once a position limit is specified, the DMC-18x2 will not accept position commands beyond the limit. Motion beyond the limit is also prevented.

Example:

DP0,0,0	Define Position
BL -2000,-4000,-8000	Set Reverse position limit
FL 2000,4000,8000	Set Forward position limit
JG 2000,2000,2000	Jog
BG XYZ	Begin

Execution of the above example will cause the motor to slew at the given jog speed until the forward position limit is reached. Motion will stop once the limit is hit.

Off-On-Error

The DMC-18x2 controller has a built in function which can turn off the motors under certain error conditions. This function is know as 'Off-On-Error". To activate the OE function for each axis, specify 1 for X,Y,Z, and W axes. To disable this function, specify 0 for the axes. When the function is enabled, the corresponding motor will be disabled under the following 3 conditions:

1. The position error for the specified axis exceeds the limit set with the command, ER
2. The abort command is given
3. The abort input is activated with a low signal.

Note: If the motors are disabled while they are moving, they may 'coast' to a stop because they are no longer under servo control.

To re-enable the system, use the Servo Here (SH) command. The SH command will clear any position error and reset the commanded position to the actual position.

Examples:

OE 1,1,1,1	Enable off-on-error for X,Y,Z, and W
OE 0,1,0,1	Enable off-on-error for Y and W axes and disable off-on-error for X and Z axes

Automatic Error Routine

The #POSERR label causes the statements following to be automatically executed if the error on any axis exceeds the error limit specified by ER. The error routine should be closed with the RE command. RE will cause the main program to be resumed where left off.

NOTE: The Error Subroutine will be entered again unless the error condition is gone.

Example:

#A;JP #A;EN	"Dummy" program
#POSERR	Start error routine on error
MG "error"	Send message
SB 1	Fire relay
STX	Stop motor
AMX	After motor stops
SHX	Servo motor here to clear error
RE	Return to main program

***NOTE**: An applications program must be executing for the #POSERR routine to function.*

Limit Switch Routine

The DMC-18x2 provides forward and reverse limit switches which inhibit motion in the respective direction. There is also a special label for automatic execution of a limit switch subroutine. The #LIMSWI label specifies the start of the limit switch subroutine. This label causes the statements following to be automatically executed if any limit switch is activated. The RE command ends the subroutine and resumes the main program where it left off.

The state of the forward and reverse limit switches may also be interrogated or used in a conditional statement. The _LR condition specifies the reverse limit and _LF specifies the forward limit. X,Y,Z, or W following _LR or _LF specifies the axis. The CN command can be used to configure the polarity of the limit switches.

Limit Switch Example:

#A;JP #A;EN	Dummy Program
#LIMSWI	Limit Switch Utility
V1=_LFX	Check state of forward limit
V2=_LRX	Check state of reverse limit
JP#LF,V1=0	Jump to #LF if forward limit = low
JP#LR,V2=0	Jump to #LR if reverse limit = low
JP#END	Jump to end
#LF	#LF
MG "FORWARD LIMIT"	Send message
STX;AMX	Stop motion
PR-1000;BGX;AMX	Move in reverse
JP#END	End
#LR	#LR
MG "REVERSE LIMIT"	Send message
STX;AMX	Stop motion
PR1000;BGX;AMX	Move forward
#END	End
RE	Return to main program

NOTE: An applications program must be executing for #LIMSWI to function.

Chapter 9 Troubleshooting

Overview

The following discussion may help you get your system running if a problem is encountered.

Potential problems have been divided into groups as follows:

1. Installation
2. Communication
3. Stability and Compensation
4. Operation

The various symptoms along with the cause and the remedy are described in the following tables.

Installation

SYMPTOM	CAUSE	REMEDY
Motor runs away when connected to amplifier with no additional inputs.	Amplifier offset too large.	Adjust amplifier offset
Same as above, but offset adjustment does not stop the motor.	Damaged amplifier.	Replace amplifier.
Controller does not read changes in encoder position.	Wrong encoder connections.	Check encoder wiring.
Same as above	Bad encoder	Check the encoder signals. Replace encoder if necessary.
Same as above	Bad controller	Connect the encoder to different axis input. If it works, controller failure. Repair or replace.

Communication

SYMPTOM	CAUSE	REMEDY

Using DMC Smart Terminal, DMCDOS, or WSDK cannot communicate with the controller.	Plug and Play installation did not proceed properly	Check first that Dmc1802.INF was used to install the controller. Next check the controller registry to see if the controller was automatically added and an address selected.

Stability

SYMPTOM	CAUSE	REMEDY
Motor runs away when the loop is closed.	Wrong feedback polarity. (Positive Feedback)	Invert the polarity of the loop by inverting the motor leads (brush type) or the encoder (channel A+, B+ if single ended; channel A+, A- if differential)
Motor oscillates.	Too high gain or too little damping.	Decrease KI and KP. Increase KD.

Operation

SYMPTOM	CAUSE	REMEDY
Controller rejects command. Responded with a ?	Anything.	Interrogate the cause with TC or TC1.
Motor does not start or complete a move.	Noise on limit switches stops the motor. Noise on the abort line aborts the motion.	To check the cause, interrogate the stop code (SC). If caused by limit switch or abort line noise, reduce noise.
During a periodic operation, motor drifts slowly.	Encoder noise	Interrogate the position periodically. If controller states that the position is the same at different locations it implies encoder noise. Also use a scope to see the noise. Reduce noise. Use differential encoder inputs.
Same as above.	Programming error.	Avoid resetting position error at end of move with SH command.

Chapter 10 Theory of Operation

Overview

The following discussion covers the operation of motion control systems. A typical motion control system consists of the elements shown in Fig 10.1.

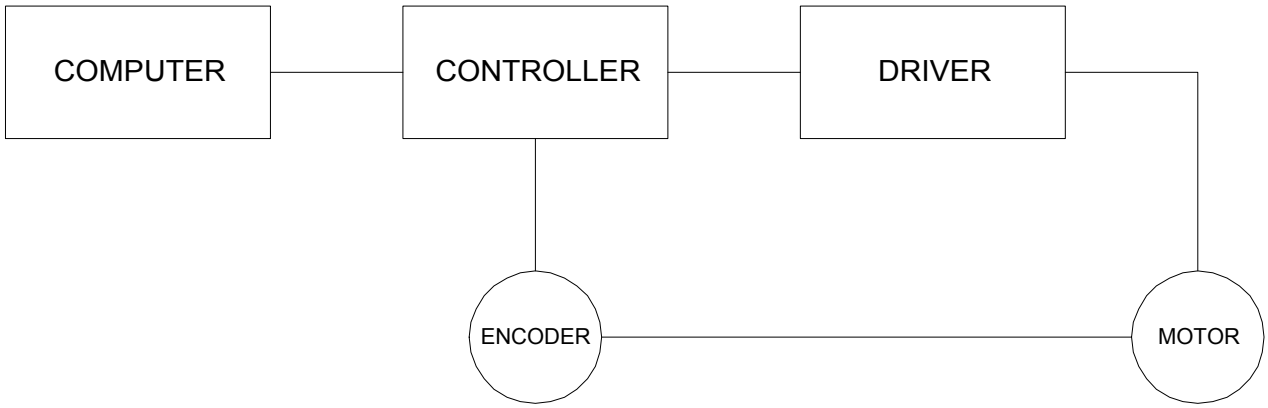

Figure 10.1 - Elements of Servo Systems

The operation of such a system can be divided into three levels, as illustrated in Fig. 10.2. The levels are:

1. Closing the Loop
2. Motion Profiling
3. Motion Programming

The first level, the closing of the loop, assures that the motor follows the commanded position. This is done by closing the position loop using a sensor. The operation at the basic level of closing the loop involves the subjects of modeling analysis, and design. These subjects will be covered in the following discussions.

The motion profiling is the generation of the desired position function. This function, R(t), describes where the motor should be at every sampling period. Note that the profiling and the closing of the loop are independent functions. The profiling function determines where the motor should be and the closing of the loop forces the motor to follow the commanded position

The highest level of control is the motion program. This can be stored in the host computer or in the controller. This program describes the tasks in terms of the motors that need to be controlled, the distances and the speed.

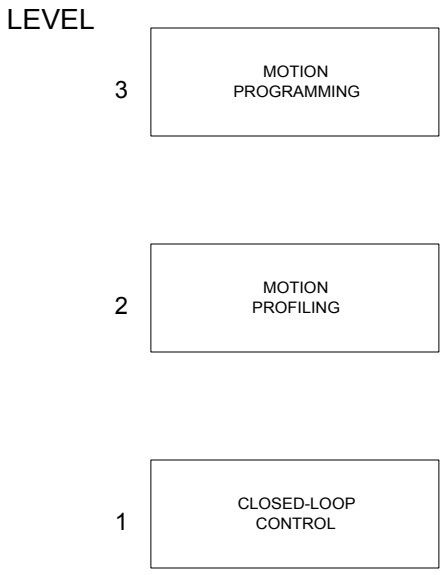

Figure 10.2 - Levels of Control Functions

The three levels of control may be viewed as different levels of management. The top manager, the motion program, may specify the following instruction, for example.

```
PR 6000,4000
SP 20000,20000
AC 200000,00000
BG X
AD 2000
BG Y
EN
```

This program corresponds to the velocity profiles shown in Fig. 10.3. Note that the profiled positions show where the motors must be at any instant of time.

Finally, it remains up to the servo system to verify that the motor follows the profiled position by closing the servo loop.

The following section explains the operation of the servo system. First, it is explained qualitatively, and then the explanation is repeated using analytical tools for those who are more theoretically inclined.

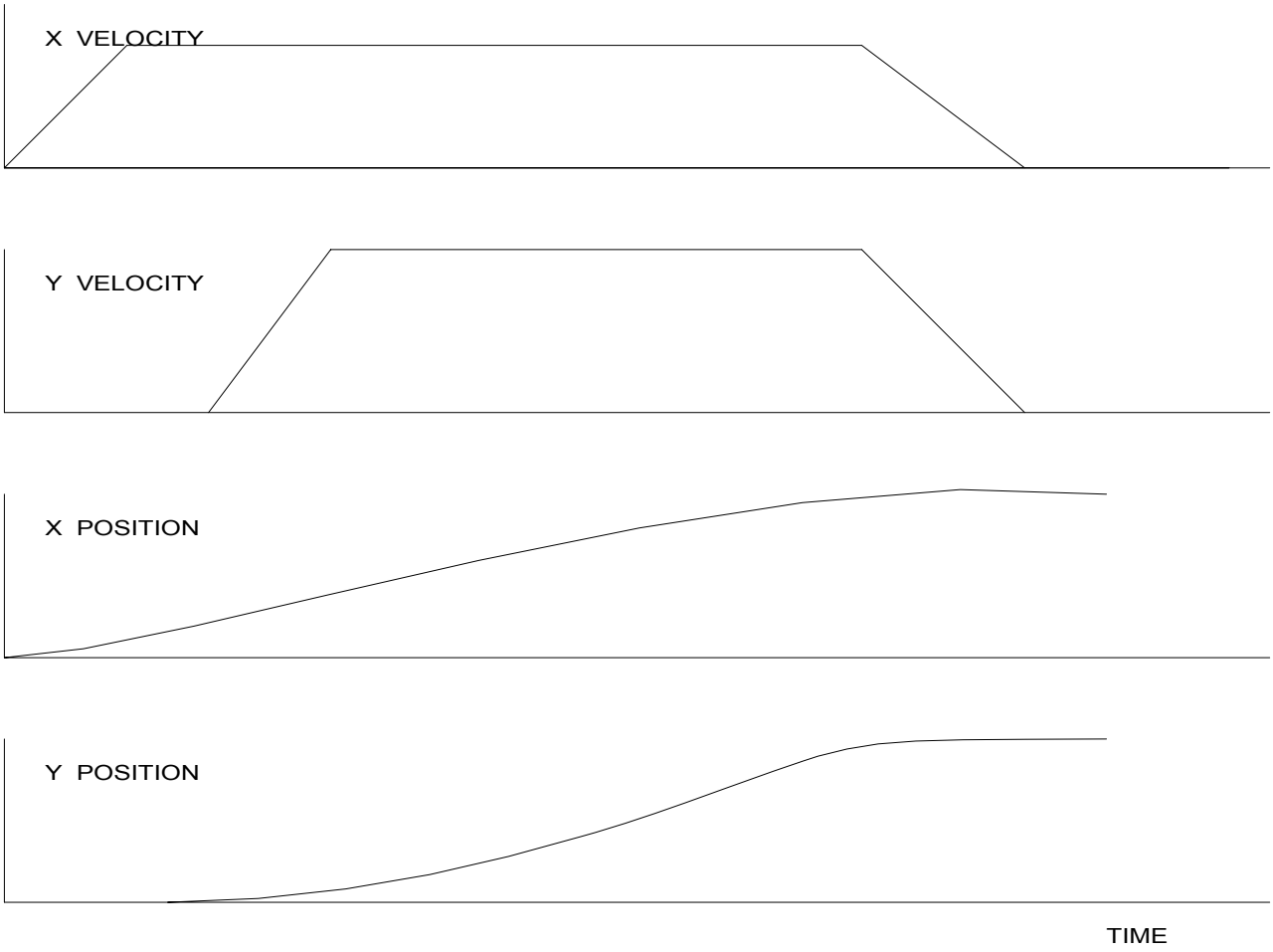

Figure 10.3 - Velocity and Position Profiles

Operation of Closed-Loop Systems

To understand the operation of a servo system, we may compare it to a familiar closed-loop operation, adjusting the water temperature in the shower. One control objective is to keep the temperature at a comfortable level, say 90 degrees F. To achieve that, our skin serves as a temperature sensor and reports to the brain (controller). The brain compares the actual temperature, which is called the feedback signal, with the desired level of 90 degrees F. The difference between the two levels is called the error signal. If the feedback temperature is too low, the error is positive, and it triggers an action which raises the water temperature until the temperature error is reduced sufficiently.

The closing of the servo loop is very similar. Suppose that we want the motor position to be at 90 degrees. The motor position is measured by a position sensor, often an encoder, and the position feedback is sent to the controller. Like the brain, the controller determines the position error, which is the difference between the commanded position of 90 degrees and the position feedback. The controller then outputs a signal that is proportional to the position error. This signal produces a proportional current in the motor, which causes a motion until the error is reduced. Once the error becomes small, the resulting current will be too small to overcome the friction, causing the motor to stop.

The analogy between adjusting the water temperature and closing the position loop carries further. We have all learned the hard way, that the hot water faucet should be turned at the "right" rate. If you turn it too slowly, the temperature response will be slow, causing discomfort. Such a slow reaction is called an overdamped response.

The results may be worse if we turn the faucet too fast. The overreaction results in temperature oscillations. When the response of the system oscillates, we say that the system is unstable. Clearly, unstable responses are bad when we want a constant level.

What causes the oscillations? The basic cause for the instability is a combination of delayed reaction and high gain. In the case of the temperature control, the delay is due to the water flowing in the pipes. When the human reaction is too strong, the response becomes unstable.

Servo systems also become unstable if their gain is too high. The delay in servo systems is between the application of the current and its effect on the position. Note that the current must be applied long enough to cause a significant effect on the velocity, and the velocity change must last long enough to cause a position change. This delay, when coupled with high gain, causes instability.

This motion controller includes a special filter which is designed to help the stability and accuracy. Typically, such a filter produces, in addition to the proportional gain, damping and integrator. The combination of the three functions is referred to as a PID filter.

The filter parameters are represented by the three constants KP, KI and KD, which correspond to the proportional, integral and derivative term respectively.

The damping element of the filter acts as a predictor, thereby reducing the delay associated with the motor response.

The integrator function, represented by the parameter KI, improves the system accuracy. With the KI parameter, the motor does not stop until it reaches the desired position exactly, regardless of the level of friction or opposing torque.

The integrator also reduces the system stability. Therefore, it can be used only when the loop is stable and has a high gain.

The output of the filter is applied to a digital-to-analog converter (DAC). The resulting output signal in the range between +10 and -10 Volts is then applied to the amplifier and the motor.

The motor position, whether rotary or linear is measured by a sensor. The resulting signal, called position feedback, is returned to the controller for closing the loop.

The following section describes the operation in a detailed mathematical form, including modeling, analysis and design.

System Modeling

The elements of a servo system include the motor, driver, encoder and the controller. These elements are shown in Fig. 10.4. The mathematical model of the various components is given below.

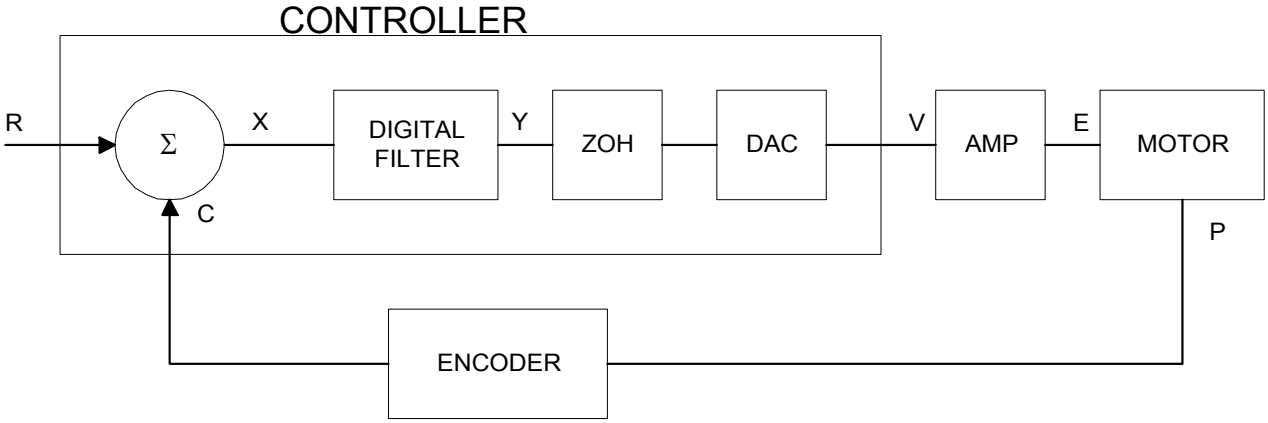

Figure 10.4 - Functional Elements of a Motion Control System

Motor-Amplifier

The motor amplifier may be configured in three modes:

1. Voltage Drive
2. Current Drive
3. Velocity Loop

The operation and modeling in the three modes is as follows:

Voltage Drive

The amplifier is a voltage source with a gain of Kv [V/V]. The transfer function relating the input voltage, V, to the motor position, P, is

$$P/V = K_V / \left[K_t S (ST_m + 1)(ST_e + 1) \right]$$

where

$$T_m = RJ / K_t^2 \quad [s]$$

and

$$T_e = L/R \quad [s]$$

and the motor parameters and units are

K_t	Torque constant [Nm/A]
R	Armature Resistance Ω
J	Combined inertia of motor and load [kg.m^2]
L	Armature Inductance [H]

When the motor parameters are given in English units, it is necessary to convert the quantities to MKS units. For example, consider a motor with the parameters:

K_t = 14.16 oz - in/A = 0.1 Nm/A

R = 2 Ω

J = 0.0283 oz-in-s^2 = 2.10^{-4} kg . m^2

L = 0.004H

Then the corresponding time constants are

T_m = 0.04 sec

and

T_e = 0.002 sec

Assuming that the amplifier gain is Kv = 4, the resulting transfer function is

P/V = 40/[s(0.04s+1)(0.002s+1)]

Current Drive

The current drive generates a current I, which is proportional to the input voltage, V, with a gain of Ka. The resulting transfer function in this case is

$$P/V = K_a K_t / Js^2$$

where Kt and J are as defined previously. For example, a current amplifier with K_a = 2 A/V with the motor described by the previous example will have the transfer function:

$$P/V = 1000/s^2 \qquad [rad/V]$$

If the motor is a DC brushless motor, it is driven by an amplifier that performs the commutation. The combined transfer function of motor amplifier combination is the same as that of a similar brush motor, as described by the previous equations.

Velocity Loop

The motor driver system may include a velocity loop where the motor velocity is sensed by a tachometer and is fed back to the amplifier. Such a system is illustrated in Fig. 10.5. Note that the transfer function between the input voltage V and the velocity ω is:

$$\omega /V = [K_a K_t/Js]/[1+K_a K_t K_g/Js] = 1/[K_g(sT_1+1)]$$

where the velocity time constant, T1, equals

$$T1 = J/K_a K_t K_g$$

This leads to the transfer function

$$P/V = 1/[K_g s(sT1+1)]$$

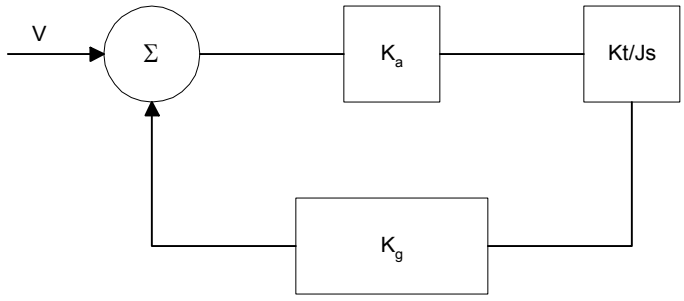

Figure 10.5 - Elements of velocity loops

The resulting functions derived above are illustrated by the block diagram of Fig. 10.6.

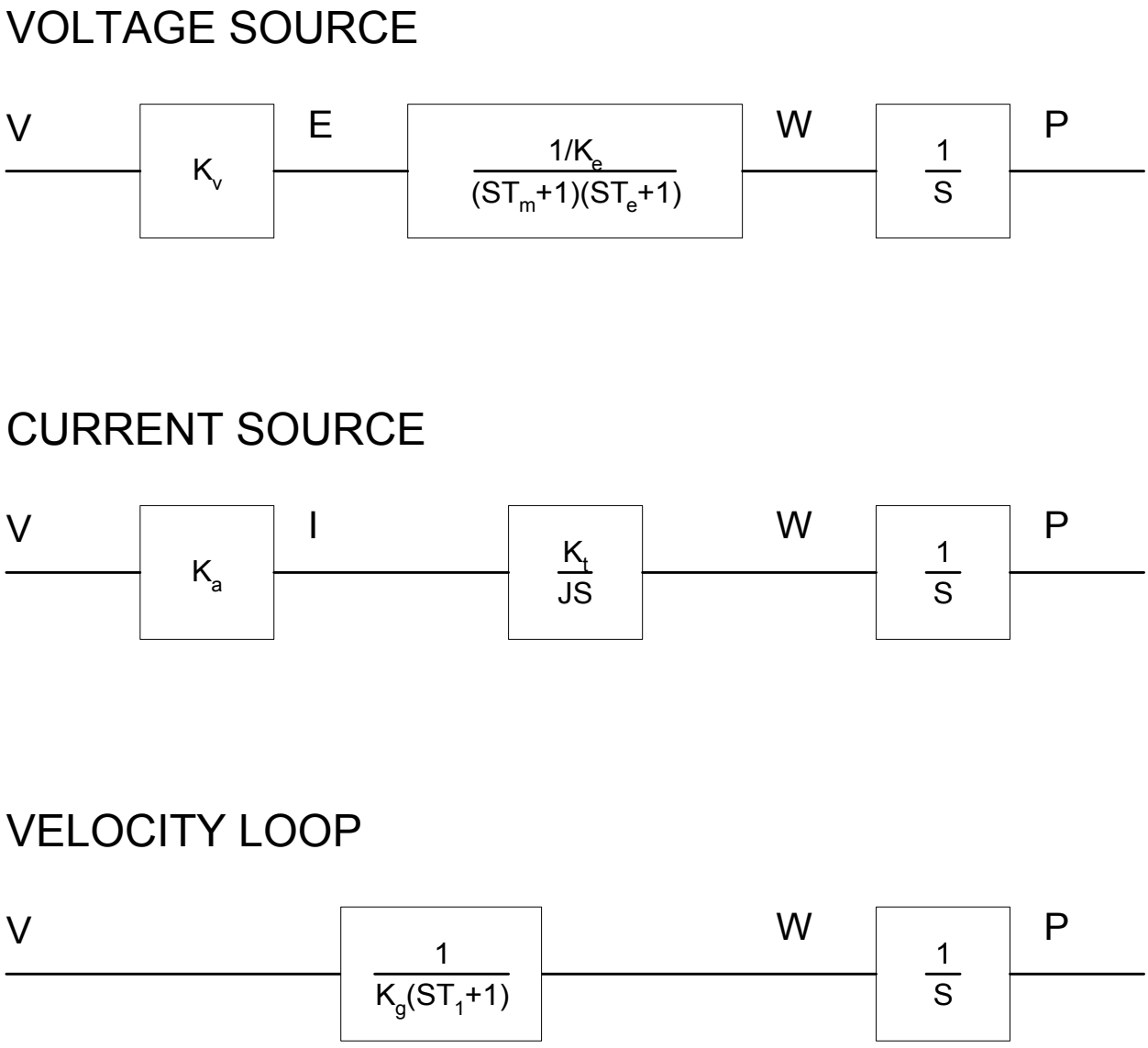

Figure 10.6 - Mathematical model of the motor and amplifier in three operational modes

Encoder

The encoder generates N pulses per revolution. It outputs two signals, Channel A and B, which are in quadrature. Due to the quadrature relationship between the encoder channels, the position resolution is increased to 4N quadrature counts/rev.

The model of the encoder can be represented by a gain of

$K_f = 4N/2\pi$ [count/rad]

For example, a 1000 lines/rev encoder is modeled as

$K_f = 638$

DAC

The DAC or D-to-A converter converts a 16-bit number to an analog voltage. The input range of the numbers is 65536 and the output voltage range is +/-10V or 20V. Therefore, the effective gain of the DAC is

$$K = 20/65536 = 0.0003 \quad [V/count]$$

Digital Filter

The digital filter has a transfer function of $D(z) = [K(z-A)/z + Cz/z-1] * (1-B)/(Z-B)$ and a sampling time of T.

The filter parameters, K, A, C and P are selected by the instructions KP, KD, KI and PL, respectively. The relationship between the filter coefficients and the instructions are:

$K = (KP + KD) \cdot 4$

$A = KD/(KP + KD)$

$C = KI/2$

$B = PL$

This filter includes a lead compensation, an integrator and a low pass filter. It is equivalent to a continuous PID filter with a transfer function G(s).

$$G(s) = (P + sD + I/s) * a/(S+a)$$

$P = 4KP$

$D = 4T \cdot KD$

$I = KI/2T$

$a = (1-B)/T$

For example, if the filter parameters of the DMC-18x2 are

$KP = 4$

$KD = 36$

$KI = 2$

$PL = 0.75$

$T = 0.001$ s

the digital filter coefficients are

$K = 160$

$A = 0.9$

$C = 1$

$a = 250$ rad/s

and the equivalent continuous filter, G(s), is

$$G(s) = [16 + 0.144s + 1000/s\} * 250/ (s+250)$$

ZOH

The ZOH, or zero-order-hold, represents the effect of the sampling process, where the motor command is updated once per sampling period. The effect of the ZOH can be modeled by the transfer function

$$H(s) = 1/(1+sT/2)$$

If the sampling period is T = 0.001, for example, H(s) becomes:

$$H(s) = 2000/(s+2000)$$

However, in most applications, H(s) may be approximated as one.

This completes the modeling of the system elements. Next, we discuss the system analysis.

System Analysis

To analyze the system, we start with a block diagram model of the system elements. The analysis procedure is illustrated in terms of the following example.

Consider a position control system with the DMC-18x2 controller and the following parameters:

$K_t = 0.1$	Nm/A	Torque constant
$J = 2.10^{-4}$	$kg.m^2$	System moment of inertia
R = 2	Ω	Motor resistance
$K_a = 4$	Amp/Volt	Current amplifier gain
KP = 12.5		Digital filter gain
KD = 245		Digital filter zero
KI = 0		No integrator
N = 500	Counts/rev	Encoder line density
T = 1	ms	Sample period

The transfer function of the system elements are:

Motor

$$M(s) = P/I = Kt/Js2 = 500/s^2 \ [rad/A]$$

Amp

$$K_a = 4 \ [Amp/V]$$

DAC

$$K_d = 0.0003 \ [V/count]$$

Encoder

$$K_f = 4N/2\pi = 318 \ [count/rad]$$

ZOH

$$2000/(s+2000)$$

Digital Filter

$$KP = 12.5, \ KD = 245, \ T = 0.001$$

Therefore,

$$D(z) = 1030 \ (z-0.95)/Z$$

Accordingly, the coefficients of the continuous filter are:

P = 50

D = 0.98

The filter equation may be written in the continuous equivalent form:

$G(s) = 50 + 0.98s = .098\ (s+51)$

The system elements are shown in Fig. 10.7.

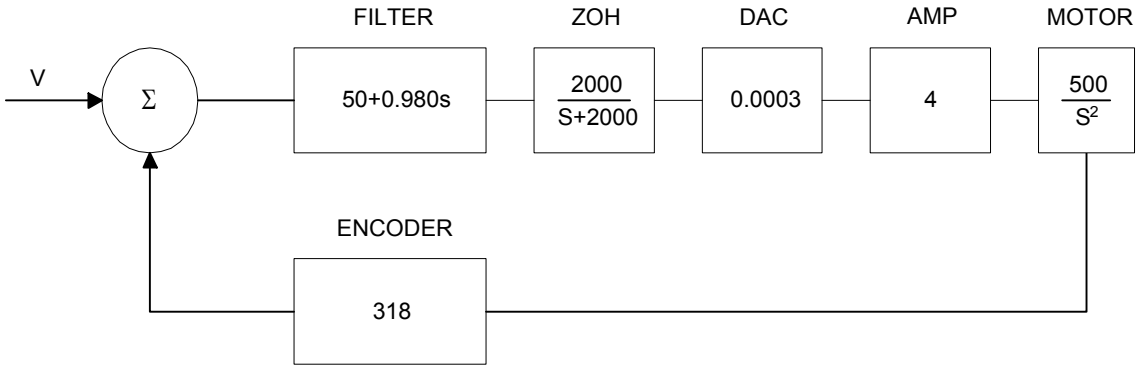

Figure 10.7 - Mathematical model of the control system

The open loop transfer function, A(s), is the product of all the elements in the loop.

$A = 390{,}000\ (s+51)/[s^2(s+2000)]$

To analyze the system stability, determine the crossover frequency, ω_c at which $A(j\ \omega_c)$ equals one. This can be done by the Bode plot of $A(j\ \omega_c)$, as shown in Fig. 10.8.

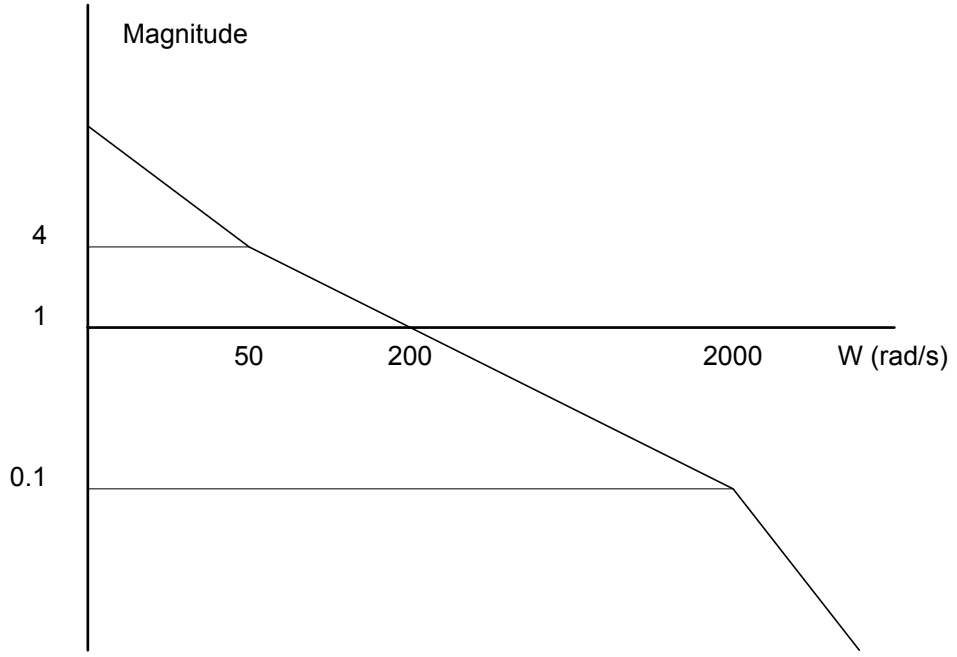

Figure 10.8 - Bode plot of the open loop transfer function

For the given example, the crossover frequency was computed numerically resulting in 200 rad/s.

Next, we determine the phase of A(s) at the crossover frequency.

$$A(j200) = 390{,}000\ (j200+51)/[(j200)^2\ .\ (j200 + 2000)]$$

$$\alpha = \text{Arg}[A(j200)] = \tan^{-1}(200/51) - 180° - \tan^{-1}(200/2000)$$

$$\alpha = 76° - 180° - 6° = -110°$$

Finally, the phase margin, PM, equals

$$PM = 180° + \alpha = 70°$$

As long as PM is positive, the system is stable. However, for a well damped system, PM should be between 30 degrees and 45 degrees. The phase margin of 70 degrees given above indicated overdamped response.

Next, we discuss the design of control systems.

System Design and Compensation

The closed-loop control system can be stabilized by a digital filter, which is preprogrammed in the DMC-18x2 controller. The filter parameters can be selected by the user for the best compensation. The following discussion presents an analytical design method.

The Analytical Method

The analytical design method is aimed at closing the loop at a crossover frequency, ω_c, with a phase margin PM. The system parameters are assumed known. The design procedure is best illustrated by a design example.

Consider a system with the following parameters:

K_t	Nm/A	Torque constant
$J = 2.10^{-4}$	$kg.m^2$	System moment of inertia
$R = 2$	Ω	Motor resistance
$K_a = 2$	Amp/Volt	Current amplifier gain
$N = 1000$	Counts/rev	Encoder line density

The DAC of the DMC-18x2 outputs +/-10V for a 14-bit command of +/-8192 counts.

The design objective is to select the filter parameters in order to close a position loop with a crossover frequency of ω_c = 500 rad/s and a phase margin of 45 degrees.

The first step is to develop a mathematical model of the system, as discussed in the previous system.

Motor

$$M(s) = P/I = K_t/Js^2 = 1000/s^2$$

Amp

$$K_a = 2 \qquad [Amp/V]$$

DAC

$$K_d = 10/32768 = .0003$$

Encoder

$K_f = 4N/2\pi = 636$

ZOH

$H(s) = 2000/(s+2000)$

Compensation Filter

$G(s) = P + sD$

The next step is to combine all the system elements, with the exception of G(s), into one function, L(s).

$L(s) = M(s)\, K_a\, K_d\, K_f\, H(s) = 3.17 * 10^6/[s^2(s+2000)]$

Then the open loop transfer function, A(s), is

$A(s) = L(s)\, G(s)$

Now, determine the magnitude and phase of L(s) at the frequency $\omega_c = 500$.

$L(j500) = 3.17 * 10^6/[(j500)^2\ (j500+2000)]$

This function has a magnitude of

$|L(j500)| = 0.00625$

and a phase

$Arg[L(j500)] = -180° - \tan^{-1}(500/2000) = -194°$

G(s) is selected so that A(s) has a crossover frequency of 500 rad/s and a phase margin of 45 degrees. This requires that

$|A(j500)| = 1$

$Arg\ [A(j500)] = -135°$

However, since

$A(s) = L(s)\, G(s)$

then it follows that G(s) must have magnitude of

$|G(j500)| = |A(j500)/L(j500)| = 160$

and a phase

$arg\ [G(j500)] = arg\ [A(j500)] - arg\ [L(j500)] = -135° + 194° = 59°$

In other words, we need to select a filter function G(s) of the form

$G(s) = P + sD$

so that at the frequency $\omega_c = 500$, the function would have a magnitude of 160 and a phase lead of 59 degrees.

These requirements may be expressed as:

$|G(j500)| = |P + (j500D)| = 160$

and

$arg\ [G(j500)] = \tan^{-1}[500D/P] = 59°$

The solution of these equations leads to:

$P = 160\cos 59° = 82.4$

$500D = 160\sin 59° = 137$

Therefore,

$D = 0.274$

and

$G = 82.4 + 0.2744s$

The function G is equivalent to a digital filter of the form:

$D(z) = 4KP + 4KD(1-z^{-1})$

where

$P = 4 * KP$

$D = 4 * KD * T$

and

$4 * KD = D/T$

Assuming a sampling period of T=1ms, the parameters of the digital filter are:

$KP = 20.6$

$KD = 68.6$

The DMC-18x2 can be programmed with the instruction:

KP 20.6

KD 68.6

In a similar manner, other filters can be programmed. The procedure is simplified by the following table, which summarizes the relationship between the various filters.

Equivalent Filter Form

	DMC-18x2
Digital	$D(z) = [K(z-A/z) + Cz/(z-1)] * (1-B)/(Z-B)$
Digital	$D(z) = [4\ KP + 4\ KD(1-z^{-1}) + KI/2(1-z^{-1})] * (1-B)/(Z-B)$
KP, KD, KI, PL	$K = (KP + KD) \cdot 4$
	$A = KD/(KP+KD)$
	$C = KI/2$
	$B = PL$
Continuous	$G(s) = (P + Ds + I/s) * a/S+a$
PID, T	$P = 4\ KP$
	$D = 4\ T*KD$
	$I = KI/2T$
	$a = B/2T$

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Appendices

Electrical Specifications

Servo Control

ACMD Amplifier Command:	+/-10 Volts analog signal. Resolution 16-bit DAC or .0003 Volts. 3 mA maximum
A+,A-,B+,B-,IDX+,IDX- Encoder	TTL compatible, but can accept up to +/-12 Volts. Quadrature phase on CHA,CHB. Can accept single-ended (A+,B+ only) or differential (A+,A-,B+,B-). Maximum A,B edge rate: 12 MHz. Minimum IDX pulse width: 80 nsec.

Stepper Control

Pulse	TTL (0-5 Volts) level at 50% duty cycle. 3MHz maximum step output frequency.
Direction	TTL (0-5 Volts)

Input/Output

Uncommitted Inputs, Limits, Home, Abort Inputs:	TTL
OUT[1] thru OUT[8] Outputs:	TTL.

Note: The part number for the 100-pin connector is #2-178238-9 from AMP.

Power

+3.3V	100 mA	Rev E*
+5V	750 mA	
+12V	20 mA	
-12V	20 mA	

*DMC-18x2 revision E and higher require 3.3V from the PCI bus. Order DMC-18x2-3VREG to have a regulator installed to allow 5V only supply.

Performance Specifications

	Normal	Fast Firmware
Minimum Servo Loop Update Time:		
DMC-1812	250 μsec	125 μsec
DMC-1822	250 μsec	125 μsec
DMC-1832	375 μsec	250 μsec
DMC-1842	375 μsec	250 μsec
Position Accuracy:	+/-1 quadrature count	
Velocity Accuracy:		
Long Term	Phase-locked, better than .005%	
Short Term	System dependent	
Position Range:	+/-2147483647 counts per move	
Velocity Range:	Up to 12,000,000 counts/sec servo;	
	3,000,000 pulses/sec-stepper	
Velocity Resolution:	2 counts/sec	
Motor Command Resolution:	16 bit or 0.0003 V	
Variable Range:	+/-2 billion	
Variable Resolution:	$1 \cdot 10^{-4}$	
Array Size:	8000 elements, 30 arrays	
Program Size:	1000 lines x 80 characters	

Connectors for DMC-18x2 Main Board

J1 DMC-1842 (A-D AXES) MAIN; 100-PIN HIGH DENSITY:

1	Analog Ground	51	nc
2	Ground	52	Ground
3	+5V	53	+5V
4	Error Output	54	NC
5	Reset	55	Home W
6	Encoder-Compare Output	56	Reverse limit W
7	Ground	57	Forward limit W
8	Ground	58	Home Z
9	Motor command W	59	Reverse limit Z
10	Sign W / Dir W	60	Forward limit Z
11	PWM W / Step W	61	Home Y
12	Motor command Z	62	Reverse limit Y
13	Sign Z / Dir Z	63	Forward limit Y

14 PWM Z / Step Z	64 Home X
15 Motor command Y	65 Reverse limit X
16 Sign Y/ Dir Y	66 Forward Limit X
17 PWM Y/ Step Y	68 +5V
18 Motor command X	69 NC
19 Sign X/ Dir X	70 Latch X
20 PWM X / Step X	71 Latch Y
21 Amp enable W	72 Latch Z
22 Amp enable Z	73 Latch W
23 Amp enable Y	74 Input 5
24 Amp enable X	75 Input 6
25 A+ X	76 Input 7
26 A- X	77 Input 8
27 B+ X	78 Abort
28 B- X	79 Output 1
29 I+ X	80 Output 2
30 I- X	81 Output 3
31 A+ Y	82 Output 4
32 A- Y	83 Output 5
33 B+ Y	84 Output 6
34 B- Y	85 Output 7
35 I+ Y	86 Output 8
36 I- Y	87 +5V
37 A+ Z	88 Ground
38 A- Z	89 Ground
39 B+ Z	90 Ground
40 B- Z	91 NC
41 I+ Z	92 NC
42 I- Z	93 NC
43 A+ W	94 NC
44 A- W	95 NC
45 B+ W	96 NC
46 B- W	97 NC
47 I+ W	98 NC
48 I- W	99 -12V
49 +12V	100 -12V
50 +12V	

***Notes**: X,Y,Z,W are interchangeable designations for A,B,C,D axes.*

Pin-Out Description for DMC-18x2

Outputs

Analog Motor Command	+/- 10 Volt range signal for driving amplifier. In servo mode, motor command output is updated at the controller sample rate. In the motor off mode, this output is held at the OF command level.
Amp Enable	Signal to disable and enable an amplifier. Amp Enable goes low on Abort and OE1.

PWM/STEP OUT	PWM/STEP OUT is used for directly driving power bridges for DC servo motors or for driving step motor amplifiers. For servo motors: If you are using a conventional amplifier that accepts a +/-10 Volt analog signal, this pin is not used and should be left open. The switching frequency is 16.7 Khz. The PWM output is available in two formats: Inverter and Sign Magnitude. In the Inverter mode, the PWM signal is .2% duty cycle for full negative voltage, 50% for 0 Voltage and 99.8% for full positive voltage. In the Sign Magnitude Mode (Jumper SM), the PWM signal is 0% for 0 Voltage, 99.6% for full voltage and the sign of the Motor Command is available at the sign output.
PWM/STEP OUT	For stepmotors: The STEP OUT pin produces a series of pulses for input to a step motor driver. The pulses may either be low or high. The pulse width is 50%. Upon Reset, the output will be low if the SM jumper is on. If the SM jumper is not on, the output will be Tristate.
Sign/Direction	Used with PWM signal to give the sign of the motor command for servo amplifiers or direction for step motors.
Error	The signal goes low when the position error on any axis exceeds the value specified by the error limit command, ER.
Output 1-Output 8	These 8 TTL outputs are uncommitted and may be designated by the user to toggle relays and trigger external events. The output lines are toggled by Set Bit, SB, and Clear Bit, CB, instructions. The OP instruction is used to define the state of all the bits of the Output port.

Inputs

Encoder, A+, B+	Position feedback from incremental encoder with two channels in quadrature, CHA and CHB. The encoder may be analog or TTL. Any resolution encoder may be used as long as the maximum frequency does not exceed 12,000,000 quadrature states/sec. The controller performs quadrature decoding of the encoder signals resulting in a resolution of quadrature counts (4 x encoder cycles). Note: Encoders that produce outputs in the format of pulses and direction may also be used by inputting the pulses into CHA and direction into Channel B and using the CE command to configure this mode.
Encoder Index, I+	Once-Per-Revolution encoder pulse. Used in Homing sequence or Find Index command to define home on an encoder index.
Encoder, A-, B-, I-	Differential inputs from encoder. May be input along with CHA, CHB for noise immunity of encoder signals. The CHA- and CHB- inputs are optional.
Abort	A low input stops commanded motion instantly without a controlled deceleration. Also aborts motion program.
Reset	A low input resets the state of the processor to its power-on condition. The previously saved state of the controller, along with parameter values, and saved sequences are restored.
Forward Limit Switch	When active, inhibits motion in forward direction. Also causes execution of limit switch subroutine, #LIMSWI. The polarity of the limit switch may be set with the CN command.
Reverse Limit Switch	When active, inhibits motion in reverse direction. Also causes execution of limit switch subroutine, #LIMSWI. The polarity of the limit switch may be set with the CN command.

Home Switch	Input for Homing (HM) and Find Edge (FE) instructions. Upon BG following HM or FE, the motor accelerates to slew speed. A transition on this input will cause the motor to decelerate to a stop. The polarity of the Home Switch may be set with the CN command.
Input 1 - Input 8	Uncommitted inputs. May be defined by the user to trigger events. Inputs are checked with the Conditional Jump instruction and After Input instruction or Input Interrupt. Input 1 is latch X, Input 2 is latch Y, Input 3 is latch Z and Input 4 is latch W if the high speed position latch function is enabled.
Latch	High speed position latch to capture axis position in less than 1 micro second on occurrence of latch signal. AL command arms latch. Input 1 is latch X, Input 2 is latch Y, Input 3 is latch Z and Input 4 is latch W.

Jumper Description for DMC-18x2

JUMPER	LABEL	FUNCTION (IF JUMPERED)
JP2	SMX	For each axis, the SM jumper selects the SM
	SMY	magnitude mode for servo motors or selects
	SMZ	stepper motors. If you are using stepper
	SMW	motors, SM must always be jumpered. The Analog command is not valid with SM jumpered.
	OPT	Motor Off on power-up.
JP6	MRST	Master Reset enable. Returns controller to factory default settings and erases EEPROM. Requires power-on or RESET to be activated.

Accessories and Options

DMC-1812	1- axis motion controller
DMC-1822	2- axes motion controller
DMC-1832	3- axes motion controller
DMC-1842	4- axes motion controller
Cable-100-1M	100-pin high density cable, 1 meter
Cable-100-2M	100-pin high density cable, 2 meter
Cable-100-4M	100-pin high density cable, 4 meter
ICM-2900-FL	Interconnect module with flange for mounting
ICM-2900-LAEN	Interconnect module with Low Amp Enable
ICM-2900-Opto	Interconnect module with Optoisolated digital outputs
ICM-1900	Interconnect module*
AMP-1910	Interconnect module with 1-axis power amplifier
AMP-1920	Interconnect module with 2-axes power amplifier
AMP-1930	Interconnect module with 3-axes power amplifier
AMP-1940	Interconnect module with 4-axes power amplifier
Utilities	Utilities for Plug & Play, DMCWIN, firmware
WSDK-16	Servo Design Kit for Windows 3.X

WSDK-32	Servo Design Kit for Windows NT, or higher
ActiveX Tool Kit	Visual Basic™ Tool Kit (includes OCXs)
Setup 16	Set-up software for Windows 3.X
Setup 32	Set-up software for Windows NT, or higher
CAD-to-DMC	AutoCAD® DXF translator
HPGL	HPGL translator

*The ICM-2900 or AMP-19X0 are the preferred interconnect method for a DMC-18X2.

ICM-1900 Interconnect Module

The ICM-1900 interconnect module provides easy connections between the DMC-18x2 series controllers and other system elements, such as amplifiers, encoders, and external switches. The ICM-1900 accepts the 100-pin main cable and breaks it into screw-type terminals. Each screw terminal is labeled for quick connection of system elements. A single ICM-1900 can be used for up to 4 axes.

The ICM-1900 is contained in a metal enclosure. A version of the ICM-1900 is also available with servo amplifiers (see AMP-19X0 below). The ICM-1900 can be purchased with an option to provide opto-isolation (see -OPTO option below) on the digital outputs.

Features

- Separates DMC-18x2 cable into individual screw-type terminals
- Clearly identifies all terminals
- Available with on-board servo drives (see AMP-19X0)
- Can be configured for AEN high or low

Note: The part number for the 100-pin connector is #2-178238-9 from AMP

Terminal #	Label	I/O	Description
1	+AAX	I	X Auxiliary encoder A+ , No Connection @
2	-AAX	I	X Auxiliary encoder A- , No Connection @
3	+ABX	I	X Auxiliary encoder B+ , No Connection @
4	-ABX	I	X Auxiliary encoder B- , No Connection @
5	+AAY	I	Y Auxiliary encoder A+ , No Connection @
6	-AAY	I	Y Auxiliary encoder A- , No Connection @
7	+ABY	I	Y Auxiliary encoder B+ , No Connection @
8	-ABY	I	Y Auxiliary encoder B- , No Connection @
9	+AAZ	I	Z Auxiliary encoder A+ , No Connection @
10	-AAZ	I	Z Auxiliary encoder A- , No Connection @
11	+ABZ	I	Z Auxiliary encoder B+ , No Connection @
12	-ABZ	I	Z Auxiliary encoder B- , No Connection @
13	+AAW	I	W Auxiliary encoder A+ , No Connection @
14	-AAW	I	W Auxiliary encoder A- , No Connection @
15	+ABW	I	W Auxiliary encoder B+ , No Connection @
16	-ABW	I	W Auxiliary encoder B- , No Connection @
17	GND		Signal Ground
18	+VCC		+ 5 Volts
19	OUTCOM	O	Output Common (for use with the opto-isolated output

			option)
20	ERROR	O	Error signal
21	RESET	I	Reset
22	CMP	O	Circular Compare output
23	MOCMDW	O	W axis motor command to amp input (w / respect to ground)
24	SIGNW	O	W axis sign output for input to stepper motor amp
25	PWMW	O	W axis pulse output for input to stepper motor amp
26	MOCMDZ	O	Z axis motor command to amp input (w / respect to ground)
27	SIGNZ	O	Z axis sign output for input to stepper motor amp
28	PWMZ	O	Z axis pulse output for input to stepper motor amp
29	MOCMDY	O	Y axis motor command to amp input (w / respect to ground)
30	SIGNY	O	Y axis sign output for input to stepper motor amp
31	PWMY	O	Y axis pulse output for input to stepper motor amp
32	MOCMDX	O	X axis motor command to amp input (w / respect to ground)
33	SIGNX	O	X axis sign output for input to stepper motor amp
34	PWMX	O	X axis pulse output for input to stepper motor amp
35	ISO	O	Isolated gnd used with opto-isolation *
36	+VCC	O	+ 5 Volts
37	AMPENW	O	W axis amplifier enable
38	AMPENZ	O	Z axis amplifier enable
39	AMPENY	O	Y axis amplifier enable
40	AMPENX	O	X axis amplifier enable
41	LSCOM	I	Limit Switch Common[@]
42	HOMEW	I	W axis home input
43	RLSW	I	W axis reverse limit switch input
44	FLSW	I	W axis forward limit switch input
45	HOMEZ	I	Z axis home input
46	RLSZ	I	Z axis reverse limit switch input
47	FLSZ	I	Z axis forward limit switch input
48	HOMEY	I	Y axis home input
49	RLSY	I	Y axis reverse limit switch input
50	FLSY	I	Y axis forward limit switch input
51	HOMEX	I	X axis home input
52	RLSX	I	X axis reverse limit switch input
53	FLSX	I	X axis forward limit switch input
54	+VCC		+ 5 Volts
55	GND		Signal Ground
56	INCOM	I	Input common , No Connection [@]
57	XLATCH	I	Input 1 (Used for X axis latch input)
58	YLATCH	I	Input 2 (Used for Y axis latch input)
59	ZLATCH	I	Input 3 (Used for Z axis latch input)
60	WLATCH	I	Input 4 (Used for W axis latch input)
61	IN5	I	Input 5
62	IN6	I	Input 6
63	IN7	I	Input 7

64	IN8	I	Input 8
65	ABORT	I	Abort Input
66	OUT1	O	Output 1
67	OUT2	O	Output 2
68	OUT3	O	Output 3
69	OUT4	O	Output 4
70	OUT5	O	Output 5
71	OUT6	O	Output 6
72	OUT7	O	Output 7
73	OUT8	O	Output 8
74	GND		Signal Ground
75	AN1	I	Analog Input 1 , No Connection @
76	AN2	I	Analog Input 2 , No Connection @
77	AN3	I	Analog Input 3 , No Connection @
78	AN4	I	Analog Input 4 , No Connection @
79	AN5	I	Analog Input 5 , No Connection @
80	AN6	I	Analog Input 6 , No Connection @
81	AN7	I	Analog Input 7 , No Connection @
82	AN8	I	Analog Input 8 , No Connection @
83	+MAX	I	X Main encoder A+
84	-MAX	I	X Main encoder A-
85	+MBX	I	X Main encoder B+
86	-MBX	I	X Main encoder B-
87	+INX	I	X Main encoder Index +
88	-INX	I	X Main encoder Index -
89	ANALOG GND*		Analog Ground*
90	+VCC		+ 5 Volts
91	+MAY	I	Y Main encoder A+
92	-MAY	I	Y Main encoder A-
93	+MBY	I	Y Main encoder B+
94	-MBY	I	Y Main encoder B-
95	+INY	I	Y Main encoder Index +
96	-INY	I	Y Main encoder Index -
97	+MAZ	I	Z Main encoder A+
98	-MAZ	I	Z Main encoder A-
99	+MBZ	I	Z Main encoder B+
100	-MBZ	I	Z Main encoder B-
101	+INZ	I	Z Main encoder Index +
102	-INZ	I	Z Main encoder Index -
103	GND		Signal Ground
104	+VCC		+ 5 Volts
105	+MAW	I	W Main encoder A+
106	-MAW	I	W Main encoder A-
107	+MBW	I	W Main encoder B+

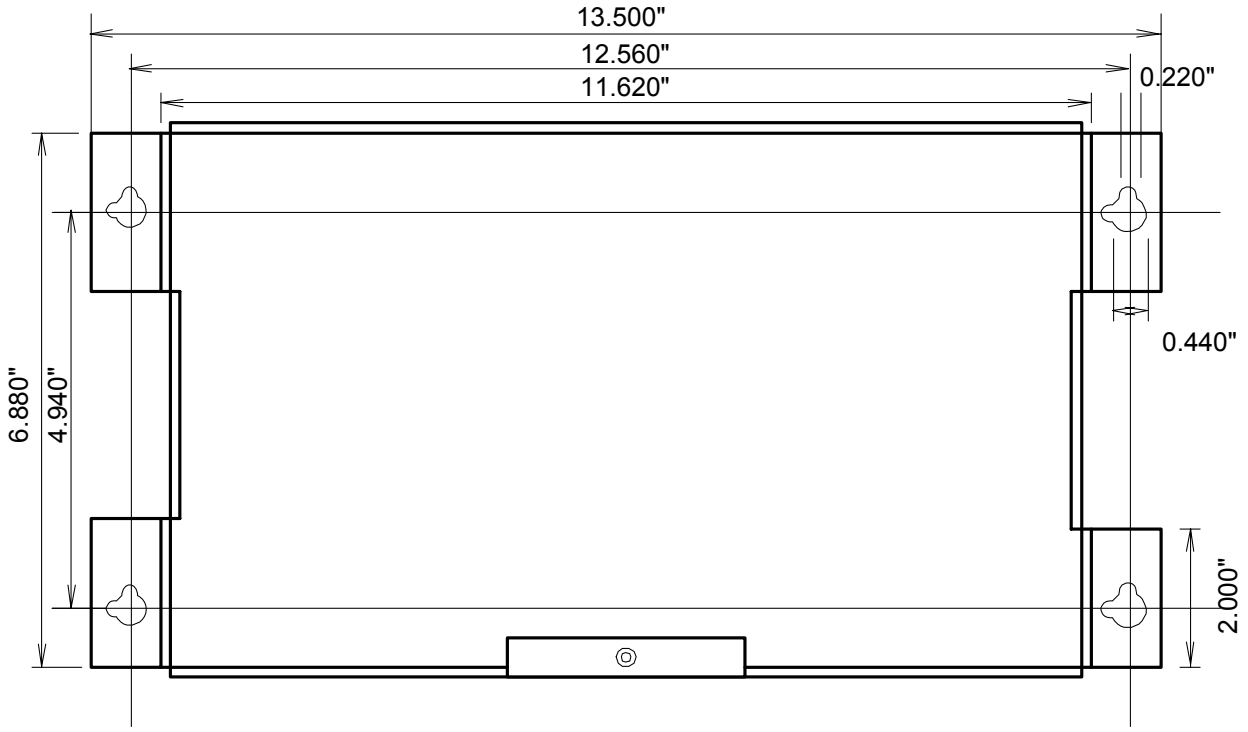
108	-MBW	I	W Main encoder B-
109	+INW	I	W Main encoder Index +
110	-INW	I	W Main encoder Index -
111	+12V		+12 Volts
112	-12V		-12 Volts

* ISOLATED GND and ANALOG GND connections added to Rev D.

@ No Connection - The DMC-18X2 does not make full use of the functionality of the ICM/AMP-19X0. These terminals refer to pins not used by the controller.

J53 provides 4 additional screw terminals for Ground Connection on Revision D.

ICM-1900 Drawing



Dimensions: 13.5” x 2.675” x 6.88”

AMP-19X0 Mating Power Amplifiers

The AMP-19X0 series are mating, brush-type servo amplifiers for the DMC-18x2. The AMP-1910 contains 1 amplifier: the AMP-1920, 2 amplifiers; the AMP-1930, 3 amplifiers; and the AMP-1940, 4 amplifiers. Each amplifier is rated for 7 amps continuous, 10 amps peak at up to 80 V. The gain of the AMP-19X0 is 1 amp/V. The AMP-19X0 requires an external DC supply. The AMP-19X0 connects directly to the DMC-18x2, and screwtype terminals are provided for connection to motors, encoders, and external switches.

Features

- 7 amps continuous, 10 amps peak; 20 to 80V
- Available with 1, 2, 3, or 4 amplifiers
- Connects directly to DMC-18x2 series controllers
- Screw-type terminals for easy connection to motors, encoders, and switches
- Steel mounting plate with 1/4" keyholes

Specifications

Minimum motor inductance: 1 mH

PWM frequency: 30 Khz

Ambient operating temperature: 0^o to 70^o C

Dimensions: Same as ICM-1900

Mounting: Keyholes -- 1/4" ∅

Gain: 1 amp/V

ICM-2900 Interconnect Module

The ICM-2900 interconnect module provides easy connections between the DMC-18x2 series controllers and other system elements, such as amplifiers, encoders, and external switches. The ICM-2900 accepts the 100-pin main cable and provides screw-type terminals for connections. Each screw terminal is labeled for quick connection of system elements. A single ICM-2900 can be used for up to 4 axes.

Block (4 PIN)	Label	I/O	Description
1	MOCMDZ	O	Z axis motor command to amp input (w / respect to ground)
1	SIGNZ	O	Z axis sign output for input to stepper motor amp
1	PWMZ	O	Z axis pulse output for input to stepper motor amp
1	GND	O	Signal Ground
2	MOCMDW	O	W axis motor command to amp input (w / respect to ground)
2	SIGNW	O	W axis sign output for input to stepper motor amp
2	PWMW	O	W axis pulse output for input to stepper motor amp
2	GND	O	Signal Ground
3	MOCMDX	O	X axis motor command to amp input (w / respect to ground)
3	SIGNX	O	X axis sign output for input to stepper motor amp
3	PWMX	O	X axis pulse output for input to stepper motor amp
3	GND	O	Signal Ground
4	MOCMDY	O	Y axis motor command to amp input (w / respect to ground)
4	SIGNY	O	Y axis sign output for input to stepper motor amp
4	PWMY	O	Y axis pulse output for input to stepper motor amp

4	GND	O	Signal Ground
5	OUT PWR	I	Isolated Power In for Opto-Isolation Option
5	ERROR	O	Error output
5	CMP	O	Circular Compare Output
5	OUT GND	O	Isolated Ground for Opto-Isolation Option
6	AMPENW	O	W axis amplifier enable
6	AMPENZ	O	Z axis amplifier enable
6	AMPENY	O	Y axis amplifier enable
6	AMPENX	O	X axis amplifier enable
7	OUT5	O	General Output 5
7	OUT6	O	General Output 6
7	OUT7	O	General Output 7
7	OUT8	O	General Output 8
8	OUT1	O	General Output 1
8	OUT2	O	General Output 2
8	OUT3	O	General Output 3
8	OUT4	O	General Output 4
9	+5V	O	+ 5 Volts
9	HOMEZ	I	Z axis home input
9	RLSZ	I	Z axis reverse limit switch input
9	FLSZ	I	Z axis forward limit switch input
10	LSCOM	I	Limit Switch Common Input , No Connection [@]
10	HOMEW	I	W axis home input
10	RLSW	I	W axis reverse limit switch input
10	FLSW	I	W axis forward limit switch input
11	HOMEX	I	X axis home input
11	RLSX	I	X axis reverse limit switch input
11	FLSX	I	X axis forward limit switch input
11	GND	O	Signal Ground
12	HOMEY	I	Y axis home input
12	RLSY	I	Y axis reverse limit switch input
12	FLSY	I	Y axis forward limit switch input
12	GND	O	Signal Ground
13	IN5	I	Input 5
13	IN6	I	Input 6
13	IN7	I	Input 7
13	IN8	I	Input 8
14	XLATCH	I	Input 1 (Used for X axis latch input)
14	YLATCH	I	Input 2 (Used for Y axis latch input)
14	ZLATCH	I	Input 3 (Used for Z axis latch input)
14	WLATCH	I	Input 4 (Used for W axis latch input)
15	+5V	O	+ 5 Volts
15	+12V	O	+12 Volts
15	-12V	O	-12 Volts
15	ANA GND	O	Isolated Analog Ground for Use with Analog Inputs

16	INCOM	I	Input Common For General Use Inputs [@]
16	ABORT	I	Abort Input
16	RESET	I	Reset Input
16	GND	O	Signal Ground
17	ANALOG5	I	Analog Input 5 , No Connection [@]
17	ANALOG6	I	Analog Input 6 , No Connection [@]
17	ANALOG7	I	Analog Input 7 , No Connection [@]
17	ANALOG8	I	Analog Input 8 , No Connection [@]
18	ANALOG1	I	Analog Input 1 , No Connection [@]
18	ANALOG2	I	Analog Input 2 , No Connection [@]
18	ANALOG3	I	Analog Input 3 , No Connection [@]
18	ANALOG4	I	Analog Input 4 , No Connection [@]
19	+5V	O	+ 5Volts
19	+INX	I	X Main encoder Index +
19	-INX	I	X Main encoder Index -
19	GND	O	Signal Ground
20	+MAX	I	X Main encoder A+
20	-MAX	I	X Main encoder A-
20	+MBX	I	X Main encoder B+
20	-MBX	I	X Main encoder B-
21	+5V	O	+ 5Volts
21	+INY	I	X Main encoder Index +
21	-INY	I	X Main encoder Index -
21	GND	O	Signal Ground
22	+MAY	I	X Main encoder A+
22	-MAY	I	X Main encoder A-
22	+MBY	I	X Main encoder B+
22	-MBY	I	X Main encoder B-
23	+5V	O	+ 5Volts
23	+INZ	I	X Main encoder Index +
23	-INZ	I	X Main encoder Index -
23	GND	O	Signal Ground
24	+MAZ	I	X Main encoder A+
24	-MAZ	I	X Main encoder A-
24	+MBZ	I	X Main encoder B+
24	-MBZ	I	X Main encoder B-
25	+5V	O	+ 5Volts
25	+INW	I	X Main encoder Index +
25	-INW	I	X Main encoder Index -
25	GND	O	Signal Ground
26	+MAW	I	X Main encoder A+
26	-MAW	I	X Main encoder A-
26	+MBW	I	X Main encoder B+
26	-MBW	I	X Main encoder B-

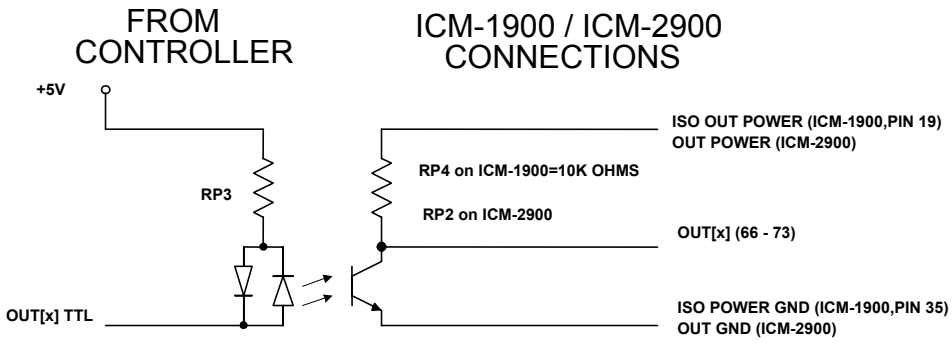
@ No Connection - The DMC-18X2 does not make full use of the functionality of the ICM-2900. These terminals refer to pins not used by the controller.

Opto-Isolated Outputs on ICM-1900/ICM-2900 (-Opto option)

The ICM/AMP 1900 and ICM-2900 modules from Galil have an option for opto-isolated outputs.

Standard Opto-Isolation and High Current Opto-isolation:

The Opto-isolation option on the ICM-1900 has 2 forms: ICM-1900 (standard) and ICM-1900hc (high current). The standard version provides outputs with 4mA drive current / output with approximately 2 usec response time. The high current version provides 25mA drive current / output with approximately 400 usec response time.



The ISO OUT POWER (OUT POWER ON ICM-2900) and ISO POWER GND (OUT GND ON ICM-2900) signals should be connected to an isolated power supply. This power supply should be used only to power the outputs in order to obtain isolation from the controller. The signal "OUT[x]" is one of the isolated digital outputs where X stands for the digital output terminals.

The default configuration is for active high outputs. If active low outputs are desired, reverse RP3 in it's socket. This will tie RP3 to GND instead of VCC, inverting the sense of the outputs.

NOTE: If power is applied to the outputs with an isolated power supply but power is not applied to the controller, the outputs will float high (unable to sink current). This may present a problem when using active high logic and care should be taken. Using active low logic should avoid any problems associated with the outputs floating high.

64 Extended I/O of the DMC-18x2 Controller

The DMC-18x2 controller offers 64 extended I/O points, which can be interfaced to Grayhill and OPTO-22 I/O mounting racks. These I/O points can be configured as inputs or outputs in 8 bit

increments through software. The I/O points are accessed through two 50-pin IDC connectors, each with 32 I/O points.

Configuring the I/O of the DMC-18x2 with DB-14064

The 64 extended I/O points of the DMC-18x2 w/DB-14064 series controller can be configured in blocks of 8. The extended I/O is denoted as blocks 2-9 or bits 17-80.

The command, CO, is used to configure the extended I/O as inputs or outputs. The CO command has one field:

CO n

Where, n is a decimal value, which represents a binary number. Each bit of the binary number represents one block of extended I/O. When set to 1, the corresponding block is configured as an output.

The least significant bit represents block 2 and the most significant bit represents block 9. The decimal value can be calculated by the following formula. $n = n_2 + 2*n_3 + 4*n_4 + 8*n_5 +16* n_6 +32* n_7 +64* n_8 +128* n_9$ where n_x represents the block. If the n_x value is a one, then the block of 8 I/O points is to be configured as an output. If the n_x value is a zero, then the block of 8 I/O points will be configured as an input. For example, if block 4 and 5 is to be configured as an output, CO 12 is issued.

8-Bit I/O Block	Block	Binary Representation	Decimal Value for Block
17-24	2	2^0	1
25-32	3	2^1	2
33-40	4	2^2	4
41-48	5	2^3	8
49-56	6	2^4	16
57-64	7	2^5	32
65-72	8	2^6	64
73-80	9	2^7	128

The simplest method for determining n:

Step 1. Determine which 8-bit I/O blocks to be configured as outputs.

Step 2. From the table, determine the decimal value for each I/O block to be set as an output.

Step 3. Add up all of the values determined in step 2. This is the value to be used for n.

For example, if blocks 2 and 3 are to be outputs, then n is 3 and the command, CO3, should be issued. Note: This calculation is identical to the formula: $n = n_2 + 2*n_3 + 4*n_4 + 8*n_5 +16* n_6 +32* n_7 +64* n_8 +128* n_9$ where n_x represents the block.

Saving the State of the Outputs in Non-Volatile Memory

The configuration of the extended I/O and the state of the outputs can be stored in the EEPROM with the BN command. If no value has been set, the default of CO 0 is used (all blocks are inputs).

Accessing extended I/O

When configured as an output, each I/O point may be defined with the SBn and CBn commands (where n=1 through 8 and 17 through 80). Outputs may also be defined with the conditional command, OBn (where n=1 through 8 and 17 through 80).

The command, OP, may also be used to set output bits, specified as blocks of data. The OP command accepts 5 parameters. The first parameter sets the values of the main output port of the controller (Outputs 1-8, block 0). The additional parameters set the value of the extended I/O as outlined:

OP m,a,b,c,d

where m is the decimal representation of the bits 1-8 (values from 0 to 255) and a,b,c,d represent the extended I/O in consecutive groups of 16 bits. (values from 0 to 65535). Arguments which are given for I/O points which are configured as inputs will be ignored. The following table describes the arguments used to set the state of outputs.

Argument	Blocks	Bits	Description
m	0	1-8	General Outputs
a	2,3	17-32	Extended I/O
b	4,5	33-48	Extended I/O
c	6,7	49-64	Extended I/O
d	8,9	65-80	Extended I/O

For example, if block 8 is configured as an output, the following command may be issued:

OP 7,,,,7

This command will set bits 1,2,3 (block 0) and bits 65,66,67 (block 8) to 1. Bits 4 through 8 and bits 68 through 80 will be set to 0. All other bits are unaffected.

When accessing I/O blocks configured as inputs, use the TIn command. The argument 'n' refers to the block to be read (n=0,2,3,4,5,6,7,8 or 9). The value returned will be a decimal representation of the corresponding bits.

Individual bits can be queried using the @IN[n] function (where n=1 through 8 or 17 through 80). If the following command is issued;

MG @IN[17]

the controller will return the state of the least significant bit of block 2 (assuming block 2 is configured as an input).

Connector Description:

The DB-14064 has two 50 Pin IDC header connectors. The connectors are compatible with I/O mounting racks such as Grayhill 70GRCM32-HL and OPTO-22 G4PB24.

Note for interfacing to OPTO-22 G4PB24: When using the OPTO-22 G4PB24 I/O mounting rack, the user will only have access to 48 of the 64 I/O points available on the controller. Block 5 and Block 9 must be configured as inputs and will be grounded by the I/O rack.

J6 50-PIN IDC

Pin	Signal	Block	Bit @IN[n], @OUT[n]	Bit No
1.	I/O	4	40	7
3.	I/O	4	39	6
5	I/O	4	38	5
7.	I/O	4	37	4

9.	I/O	4	36	3
11.	I/O	4	35	2
13.	I/O	4	34	1
15.	I/O	4	33	0
17.	I/O	3	32	7
19.	I/O	3	31	6
21.	I/O	3	30	5
23.	I/O	3	29	4
25.	I/O	3	28	3
27.	I/O	3	27	2
29.	I/O	3	26	1
31.	I/O	3	25	0
33.	I/O	2	24	7
35.	I/O	2	23	6
37.	I/O	2	22	5
39.	I/O	2	21	4
41.	I/O	2	20	3
43.	I/O	2	19	2
45.	I/O	2	18	1
47.	I/O	2	17	0
49.	+5V	-	-	-
2.	I/O	5	41	0
4.	I/O	5	42	1
6.	I/O	5	43	2
8.	I/O	5	44	3
10.	I/O	5	45	4
12.	I/O	5	46	5
14.	I/O	5	47	6
16.	I/O	5	48	7
18.	GND	-	-	-
20.	GND	-	-	-
22.	GND	-	-	-
24.	GND	-	-	-
26.	GND	-	-	-
28.	GND	-	-	-
30.	GND	-	-	-
32.	GND	-	-	-
34.	GND	-	-	-
36.	GND	-	-	-
38.	GND	-	-	-
40.	GND	-	-	-
42.	GND	-	-	-
44.	GND	-	-	-
46.	GND	-	-	-
48.	GND	-	-	-
50.	GND	-	-	-

J8 50-PIN IDC

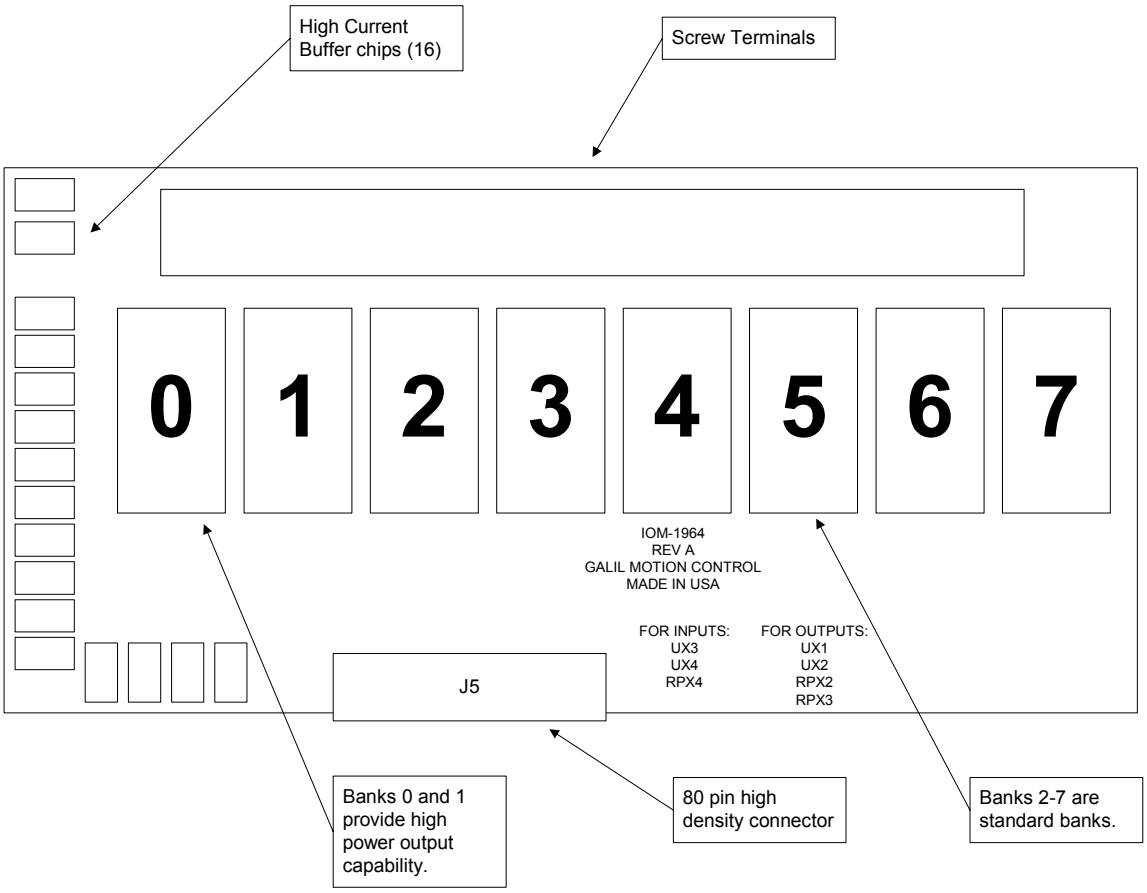
Pin	Signal	Block	Bit @IN[n], @OUT[n]	Bit No
1.	I/O	8	72	7
3.	I/O	8	71	6
5	I/O	8	70	5
7.	I/O	8	69	4
9.	I/O	8	68	3
11.	I/O	8	67	2
13.	I/O	8	66	1
15.	I/O	8	65	0
17.	I/O	7	64	7
19.	I/O	7	63	6
21.	I/O	7	62	5
23.	I/O	7	61	4
25.	I/O	7	60	3
27.	I/O	7	59	2
29.	I/O	7	58	1
31.	I/O	7	57	0
33.	I/O	6	56	7
35.	I/O	6	55	6
37.	I/O	6	54	5
39.	I/O	6	53	4
41.	I/O	6	52	3
43.	I/O	6	51	2
45.	I/O	6	50	1
47.	I/O	6	49	0
49.	+5V	-	-	-
2.	I/O	9	73	0
4.	I/O	9	74	1
6.	I/O	9	75	2
8.	I/O	9	76	3
10.	I/O	9	77	4
12.	I/O	9	78	5
14.	I/O	9	79	6
16.	I/O	9	80	7
18.	GND	-	-	-
20.	GND	-	-	-
22.	GND	-	-	-
24.	GND	-	-	-
26.	GND	-	-	-
28.	GND	-	-	-
30.	GND	-	-	-
32.	GND	-	-	-

34.	GND	-	-	-
36.	GND	-	-	-
38.	GND	-	-	-
40.	GND	-	-	-
42.	GND	-	-	-
44.	GND	-	-	-
46.	GND	-	-	-
48.	GND	-	-	-
50.	GND	-	-	-

IOM-1964 Opto-Isolation Module for Extended I/O Controllers

Description:

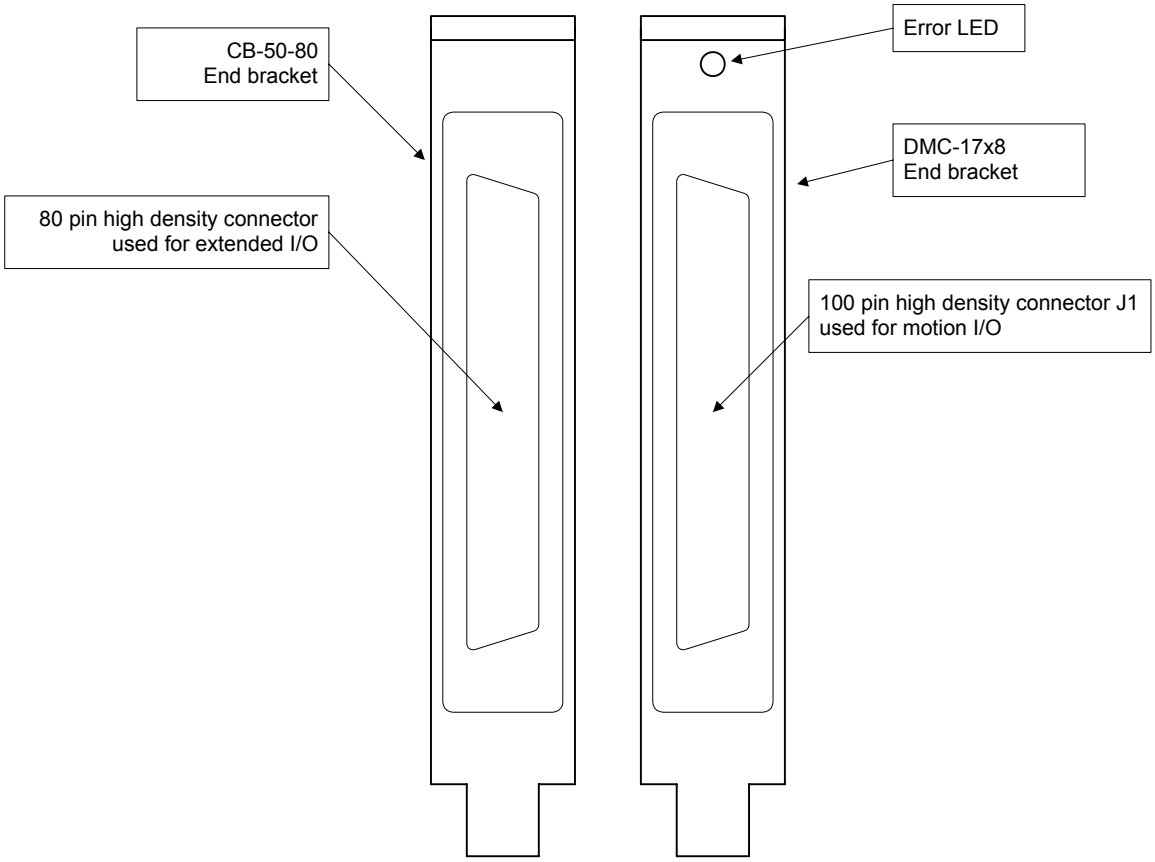
- Provides 64 optically isolated inputs and outputs, each rated for 2mA at up to 28 VDC
- Configurable as inputs or outputs in groups of eight bits
- Provides 16 high power outputs capable of up to 500mA each
- Connects to controller via 100 pin shielded cable
- All I/O points conveniently labeled
- Each of the 64 I/O points has status LED
- Dimensions 6.8” x 11.4”
- Works with extended I/O controllers



Overview

The IOM-1964 is an input/output module that connects to the DMC-18x2 motion controller and DB-14064 extended I/O daughter board cards from Galil, providing optically isolated buffers for the extended inputs and outputs of the controller. The IOM-1964 also provides 16 high power outputs capable of 500mA of current per output point. The IOM-1964 splits the 64 I/O points into eight banks of eight I/O points each, corresponding to the eight banks of extended I/O on the controller. Each bank is individually configured as an input or output bank by inserting the appropriate integrated circuits and resistor packs. The hardware configuration of the IOM-1964 must match the software configuration of the controller card.

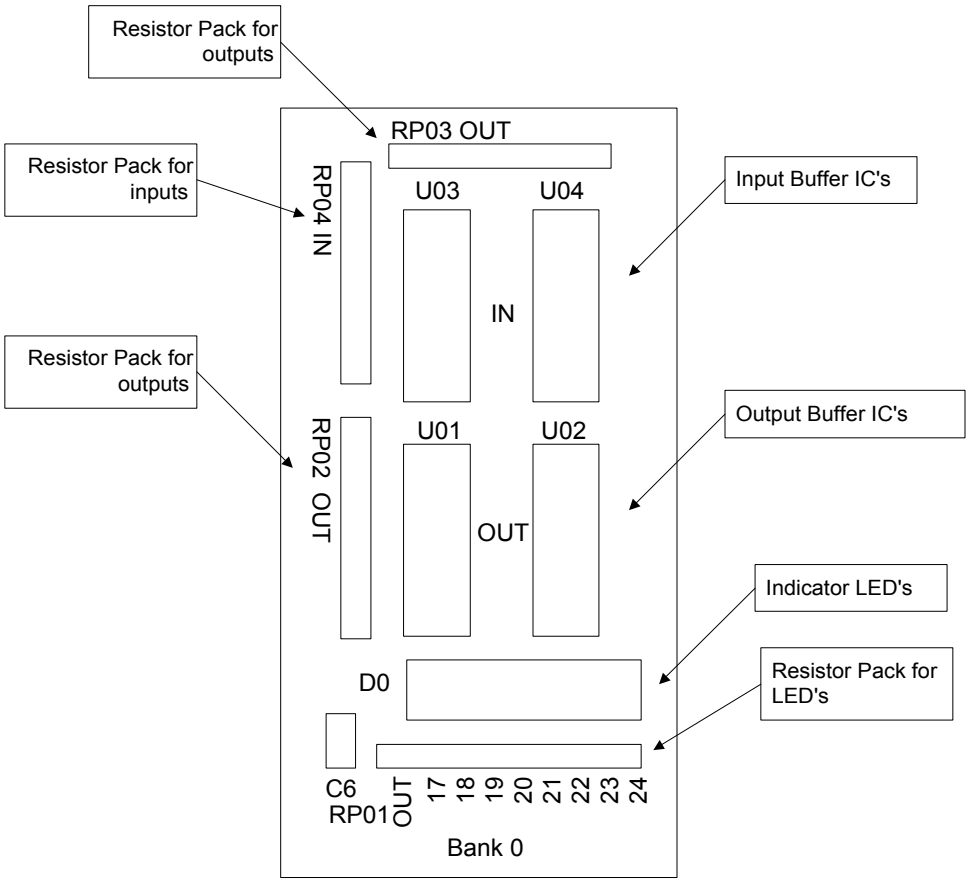
The DMC-18x2 with DB-14064, however, has an additional 64 digital input/output points than the general 8 in and 8 out, for a total of 80 input/output points. The 64 I/O points on the DMC-18x2 model controllers are attached via two 50 pin ribbon cable header connectors on the DB-14064. A CB-50-80 adapter card is used to connect the two 50 pin ribbon cables to a 80 pin high density connector similar to the main axes connector. A 80 pin shielded cable connects from the 80 pin connector of the CB-50-80 board to the 80 pin high density connector J5 on the IOM-1964.



Configuring Hardware Banks

The extended I/O on the DMC-18x2 and DB-14064 is configured using the CO command. The banks of buffers on the IOM-1964 are configured to match by inserting the appropriate IC's and resistor packs. The layout of each of the I/O banks is identical.

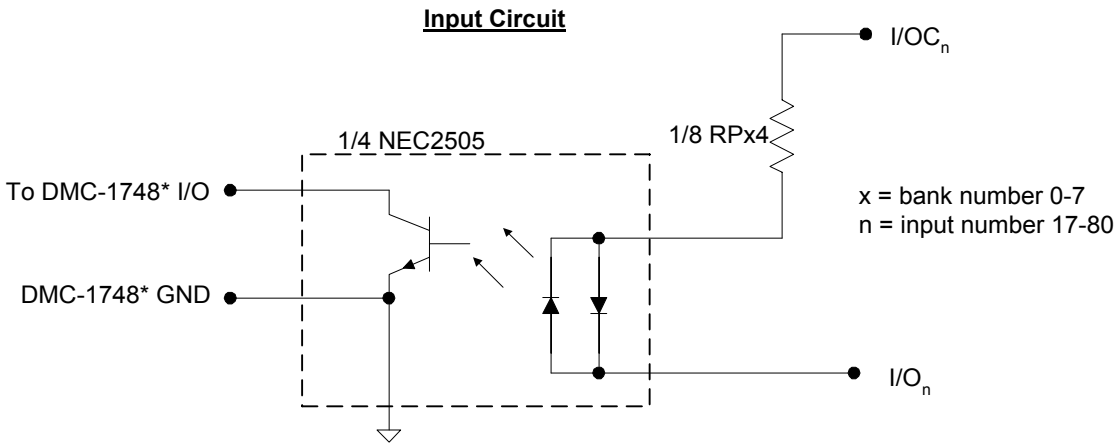
For example, here is the layout of bank 0:



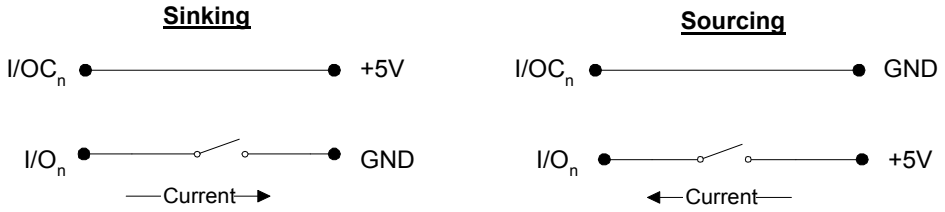
All of the banks have the same configuration pattern as diagrammed above. For example, all banks have Ux1 and Ux2 output optical isolator IC sockets, labeled in bank 0 as U01 and U02, in bank 1 as U11 and U12, and so on. Each bank is configured as inputs or outputs by inserting optical isolator IC's and resistor packs in the appropriate sockets. A group of eight LED's indicates the status of each I/O point. The numbers above the Bank 0 label indicate the number of the I/O point corresponding to the LED above it.

Digital Inputs

Configuring a bank for inputs requires that the Ux3 and Ux4 sockets be populated with NEC2505 optical isolation integrated circuits. The IOM-1964 is shipped with a default configuration of banks 2-7 configured as inputs. The output IC sockets Ux1 and Ux2 must be empty. The input IC's are labeled Ux3 and Ux4. For example, in bank 0 the IC's are U03 and U04, bank 1 input IC's are labeled U13 and U14, and so on. Also, the resistor pack RPx4 must be inserted into the bank to finish the input configuration.

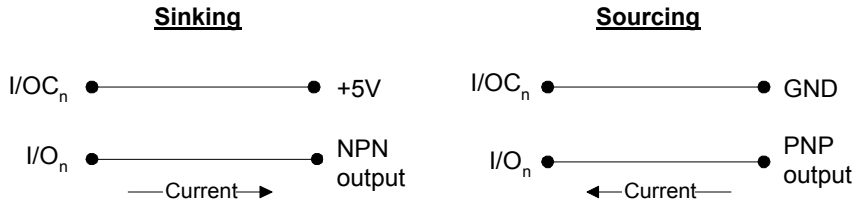


Connections to this optically isolated input circuit are done in a sinking or sourcing configuration, referring to the direction of current. Some example circuits are shown below:



There is one I/OC connection for each bank of eight inputs. Whether the input is connected as sinking or sourcing, when the switch is open no current flows and the digital input function @IN[n] returns 1. This is because of an internal pull up resistor on the DMC-17x8/DB-14064*. When the switch is closed in either circuit, current flows. This pulls the input on the DMC-17x8/DB-14064 to ground, and the digital input function @IN[n] returns 0. Note that the external +5V in the circuits above is for example only. The inputs are optically isolated and can accept a range of input voltages from 4 to 28 VDC.

Active outputs are connected to the optically isolated inputs in a similar fashion with respect to current. An NPN output is connected in a sinking configuration, and a PNP output is connected in the sourcing configuration.



Whether connected in a sinking or sourcing circuit, only two connections are needed in each case. When the NPN output is 5 volts, then no current flows and the input reads 1. When the NPN output goes to 0 volts, then it sinks current and the input reads 0. The PNP output works in a similar fashion, but the voltages are reversed i.e. 5 volts on the PNP output sources current into the digital input and the input reads 0. As before, the 5 volt is an example, the I/OC can accept between 4-28 volts DC.

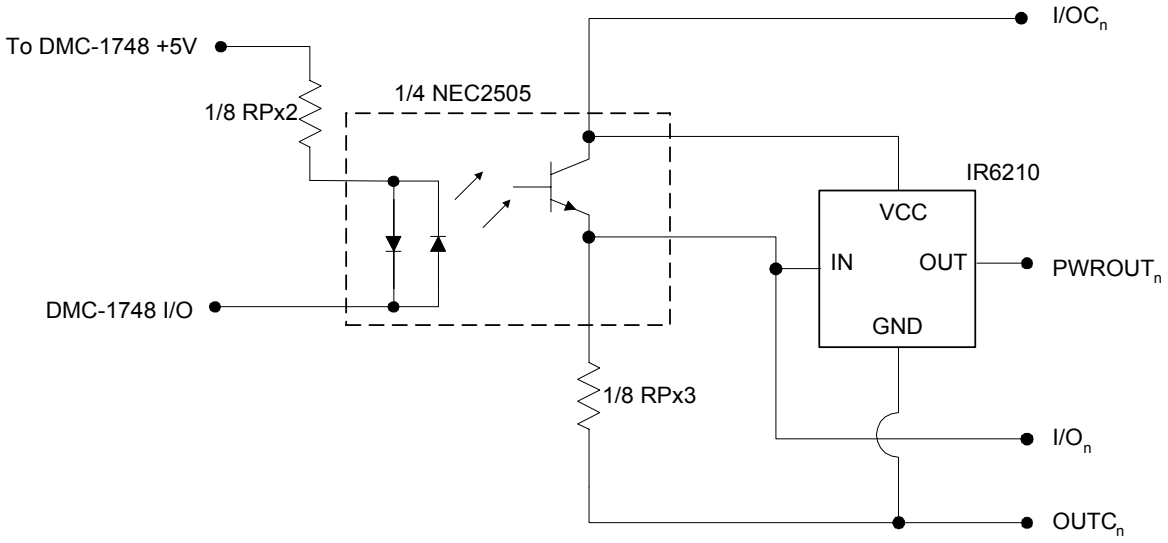
Note that the current through the digital input should be kept below 3 mA in order to minimize the power dissipated in the resistor pack. This will help prevent circuit failures. The resistor pack RPx4 is standard 1.5k ohm which is suitable for power supply voltages up to 5.5 VDC. However, use of 24 VDC for example would require a higher resistance such as a 10k ohm resistor pack.

*The 1-4 axis models of the DMC-17x8 all work with the IOM-1964, all have identical extended I/O features.

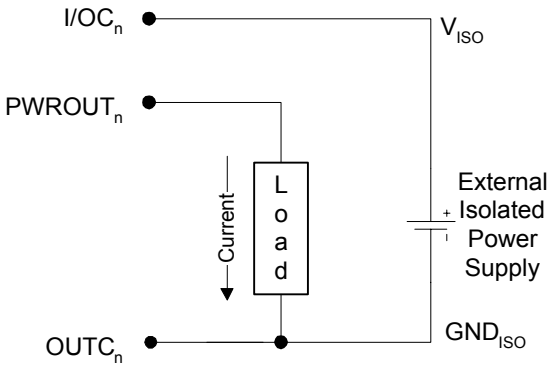
High Power Digital Outputs

The first two banks on the IOM-1964, banks 0 and 1, have high current output drive capability. The IOM-1964 is shipped with banks 0 and 1 configured as outputs. Each output can drive up to 500mA of continuous current. Configuring a bank of I/O as outputs is done by inserting the optical isolator NEC2505 IC's into the Ux1 and Ux2 sockets. The digital input IC's Ux3 and Ux4 are removed. The resistor packs RPx2 and RPx3 are inserted, and the input resistor pack RPx4 is removed.

Each bank of eight outputs shares one I/OC connection, which is connected to a DC power supply between 4 and 28 VDC. A 10k ohm resistor pack should be used for RPx3. Here is a circuit diagram:



The load is connected between the power output and output common. The I/O connection is for test purposes, and would not normally be connected. An external power supply is connected to the I/OC and OUTC terminals, which isolates the circuitry of the DMC-1748 controller/DB-14064 daughter board from the output circuit.



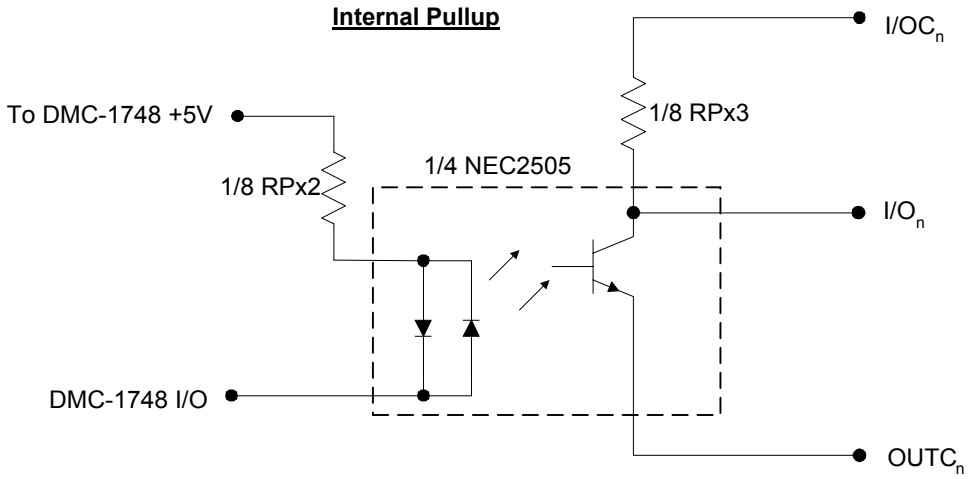
The power outputs must be connected in a driving configuration as shown on the previous page. Here are the voltage outputs to expect after the Clear Bit and Set Bit commands are given:

Output Command	Result
CB_n	$V_{pwr} = V_{iso}$
SB_n	$V_{pwr} = GND_{iso}$

Standard Digital Outputs

The I/O banks 2-7 can be configured as optically isolated digital outputs, however these banks do not have the high power capacity as in banks 0-1. In order to configure a bank as outputs, the optical isolator chips Ux1 and Ux2 are inserted, and the digital input isolator chips Ux3 and Ux4 are removed. The resistor packs RPx2 and RPx3 are inserted, and the input resistor pack RPx4 is removed.

Each bank of eight outputs shares one I/OC connection, which is connected to a DC power supply between 4 and 28 VDC. The resistor pack RPx3 is optional, used either as a pull up resistor from the output transistor's collector to the external supply connected to I/OC or the RPx3 is removed resulting in an open collector output. Here is a schematic of the digital output circuit:



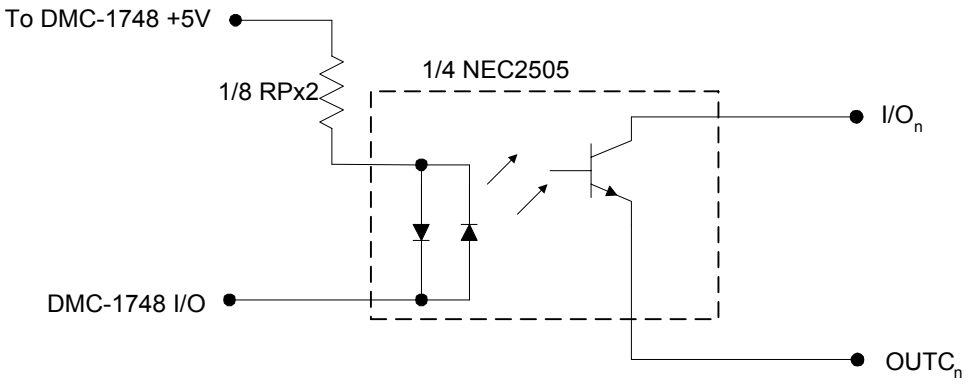
The resistor pack RPx3 limits the amount of current available to source, as well as affecting the low level voltage at the I/O output. The maximum sink current is 2mA regardless of RPx3 or I/OC voltage, determined by the NEC2505 optical isolator IC. The maximum source current is determined by dividing the external power supply voltage by the resistor value of RPx3.

The high level voltage at the I/O output is equal to the external supply voltage at I/OC. However, when the output transistor is on and conducting current, the low level output voltage is determined by three factors. The external supply voltage, the resistor pack RPx3 value, and the current sinking limit of the NEC2505 all determine the low level voltage. The sink current available from the NEC2505 is between 0 and 2mA. Therefore, the maximum voltage drop across RPx3 is calculated by multiplying the 2mA maximum current times the resistor value of RPx3. For example, if a 10k ohm resistor pack is used for RPx3, then the maximum voltage drop is 20 volts. The digital output will never drop below the voltage at OUTC, however. Therefor a 10k ohm resistor pack will result in a low level voltage of .7 to 1.0 volts at the I/O output for an external supply voltage between 4 and 21 VDC. If a supply voltage greater than 21 VDC is used, a higher value resistor pack will be required.

Output Command	Result
CB_n	$V_{out} = GND_{iso}$
SB_n	$V_{out} = V_{iso}$

The resistor pack RPx3 is removed to provide open collector outputs. The same calculations for maximum source current and low level voltage applies as in the above circuit. The maximum sink current is determined by the NEC2505, and is approximately 2mA.

Open Collector



Electrical Specifications

- I/O points, configurable as inputs or outputs in groups of 8

Digital Inputs

- Maximum voltage: 28 VDC
- Minimum input voltage: 4 VDC
- Maximum input current: 3 mA

High Power Digital Outputs

- Maximum external power supply voltage: 28 VDC
- Minimum external power supply voltage: 4 VDC
- Maximum source current, per output: 500mA
- Maximum sink current: sinking circuit inoperative

Standard Digital Outputs

- Maximum external power supply voltage: 28 VDC
- Minimum external power supply voltage: 4 VDC
- Maximum source current: limited by pull up resistor value
- Maximum sink current: 2mA

Relevant DMC Commands

CO n	Configures the 64 bits of extended I/O in 8 banks of 8 bits each. $n = n_2 + 2*n_3 + 4*n_4 + 8*n_5 + 16*n_6 + 32*n_7 + 64*n_8 + 128*n_9$ where n_x is a 1 or 0, 1 for outputs and 0 for inputs. The x is the bank number
OP	m = 8 standard digital outputs
m,n,o,p,q	n = extended I/O banks 0 & 1, outputs 17-32 o = extended I/O banks 2 & 3, outputs 33-48 p = extended I/O banks 4 & 5, outputs 49-64 q = extended I/O banks 6 & 7, outputs 65-80
SB n	Sets the output bit to a logic 1, n is the number of the output from 1 to 80.
CB n	Clears the output bit to a logic 0, n is the number of the output from 1 to 80.
OB n,m	Sets the state of an output as 0 or 1, also able to use logical conditions.
TI n	Returns the state of 8 digital inputs as binary converted to decimal, n is the bank number +2.
_TI n	Operand (internal variable) that holds the same value as that returned by TI n.
@IN[n]	Function that returns state of individual input bit, n is number of the input from 1 to 80.

Screw Terminal Listing

Rev A+B boards (orange) and Rev C boards (black) have the pinouts listed below

REV A+B TERMINAL #	REV C TERMINAL #	LABEL	DESCRIPTION	BANK
1		GND	Ground	N/A
2	2	5V	5V DC out	N/A
3	1	GND	Ground	N/A
4	4	5V	5V DC out	N/A
5	3	I/O80	I/O bit 80	7
6	6	I/O79	I/O bit 79	7
7	5	I/O78	I/O bit 78	7
8	8	I/O77	I/O bit 77	7
9	7	I/O76	I/O bit 76	7
10	10	I/O75	I/O bit 75	7
11	9	I/O74	I/O bit 74	7
12	12	I/O73	I/O bit 73	7
13	11	OUTC73-80	Out common for I/O 73-80	7
14	14	I/OC73-80	I/O common for I/O 73-80	7
15	13	I/O72	I/O bit 72	6
16	16	I/O71	I/O bit 71	6
17	15	I/O70	I/O bit 70	6
18	18	I/O69	I/O bit 69	6
19	17	I/O68	I/O bit 68	6
20	20	I/O67	I/O bit 67	6
21	19	I/O66	I/O bit 66	6
22	22	I/O65	I/O bit 65	6
23	21	OUTC65-72	Out common for I/O 65-72	6
24	24	I/OC65-72	I/O common for I/O 65-72	6

25	23	I/O64	I/O bit 64	5
26	26	I/O63	I/O bit 63	5
27	25	I/O62	I/O bit 62	5
28	28	I/O61	I/O bit 61	5
29	27	I/O60	I/O bit 60	5
30	30	I/O59	I/O bit 59	5
31	29	I/O58	I/O bit 58	5
32	32	I/O57	I/O bit 57	5
33	31	OUTC57-64	Out common for I/O 57-64	5
34	34	I/OC57-64	I/O common for I/O 57-64	5
35	33	I/O56	I/O bit 56	4
36	36	I/O55	I/O bit 55	4
37	35	I/O54	I/O bit 54	4
38	38	I/O53	I/O bit 53	4
39	37	I/O52	I/O bit 52	4
40	40	I/O51	I/O bit 51	4
41	39	I/O50	I/O bit 50	4
42	42	I/O49	I/O bit 49	4
43	41	OUTC49-56	Out common for I/O 49-56	4
44	44	I/OC49-56	I/O common for I/O 49-56	4
45	43	I/O48	I/O bit 48	3
46	46	I/O47	I/O bit 47	3
47	45	I/O46	I/O bit 46	3
48	48	I/O45	I/O bit 45	3
49	47	I/O44	I/O bit 44	3
50	50	I/O43	I/O bit 43	3
51	49	I/O42	I/O bit 42	3
52	52	I/O41	I/O bit 41	3
53	51	OUTC41-48	Out common for I/O 41-48	3
54	54	I/OC41-48	I/O common for I/O 41-48	3
55	53	I/O40	I/O bit 40	2
56	56	I/O39	I/O bit 39	2
57	55	I/O38	I/O bit 38	2
58	58	I/O37	I/O bit 37	2
59	57	I/O36	I/O bit 36	2
60	60	I/O35	I/O bit 35	2
61	59	I/O34	I/O bit 34	2
62	62	I/O33	I/O bit 33	2
63	61	OUTC33-40	Out common for I/O 33-40	2
64	64	I/OC33-40	I/O common for I/O 33-40	2
65	63	I/O32	I/O bit 32	1
66	66	I/O31	I/O bit 31	1
67	65	I/O30	I/O bit 30	1
68	68	I/O29	I/O bit 29	1
69	67	I/O28	I/O bit 28	1

70	70	I/O27	I/O bit 27	1
71	69	I/O26	I/O bit 26	1
72	72	I/O25	I/O bit 25	1
73	71	OUTC25-32	Out common for I/O 25-32	1
74	74	I/OC25-32	I/O common for I/O 25-32	1
75	73	OUTC25-32	Out common for I/O 25-32	1
76	76	I/OC25-32	I/O common for I/O 25-32	1
77	75	PWROUT32	Power output 32	1
78	78	PWROUT31	Power output 31	1
79	77	PWROUT30	Power output 30	1
80	80	PWROUT29	Power output 29	1
81	79	PWROUT28	Power output 28	1
82	82	PWROUT27	Power output 27	1
83	81	PWROUT26	Power output 26	1
84	84	PWROUT25	Power output 25	1
85	83	I/O24	I/O bit 24	0
86	86	I/O23	I/O bit 23	0
87	85	I/O22	I/O bit 22	0
88	88	I/O21	I/O bit 21	0
9	87	I/O20	I/O bit 20	0
90	90	I/O19	I/O bit 19	0
91	89	I/O18	I/O bit 18	0
92	92	I/O17	I/O bit 17	0
93	91	OUTC17-24	Out common for I/O 17-24	0
94	94	I/OC17-24	I/O common for I/O 17-24	0
95	93	OUTC17-24	Out common for I/O 17-24	0
96	96	I/OC17-24	I/O common for I/O 17-24	0
97	95	PWROUT24	Power output 24	0
98	98	PWROUT23	Power output 23	0
99	97	PWROUT22	Power output 22	0
100	100	PWROUT21	Power output 21	0
101	99	PWROUT20	Power output 20	0
102	102	PWROUT19	Power output 19	0
103	101	PWROUT18	Power output 18	0
104	104	PWROUT17	Power output 17	0
	103	GND	Ground	

Coordinated Motion - Mathematical Analysis

The terms of coordinated motion are best explained in terms of the vector motion. The vector velocity, Vs, which is also known as the feed rate, is the vector sum of the velocities along the X and Y axes, Vx and Vy.

$$Vs = \sqrt{Vx^2 + Vy^2}$$

The vector distance is the integral of Vs, or the total distance traveled along the path. To illustrate this further, suppose that a string was placed along the path in the X-Y plane. The length of that string represents the distance traveled by the vector motion.

The vector velocity is specified independently of the path to allow continuous motion. The path is specified as a collection of segments. For the purpose of specifying the path, define a special X-Y coordinate system whose origin is the starting point of the sequence. Each linear segment is specified by the X-Y coordinate of the final point expressed in units of resolution, and each circular arc is defined by the arc radius, the starting angle, and the angular width of the arc. The zero angle corresponds to the positive direction of the X-axis and the CCW direction of rotation is positive. Angles are expressed in degrees, and the resolution is 1/256th of a degree. For example, the path shown in Fig. A.2 is specified by the instructions:

```
VP          0,10000
CR          10000, 180, -90
VP          20000, 20000
```

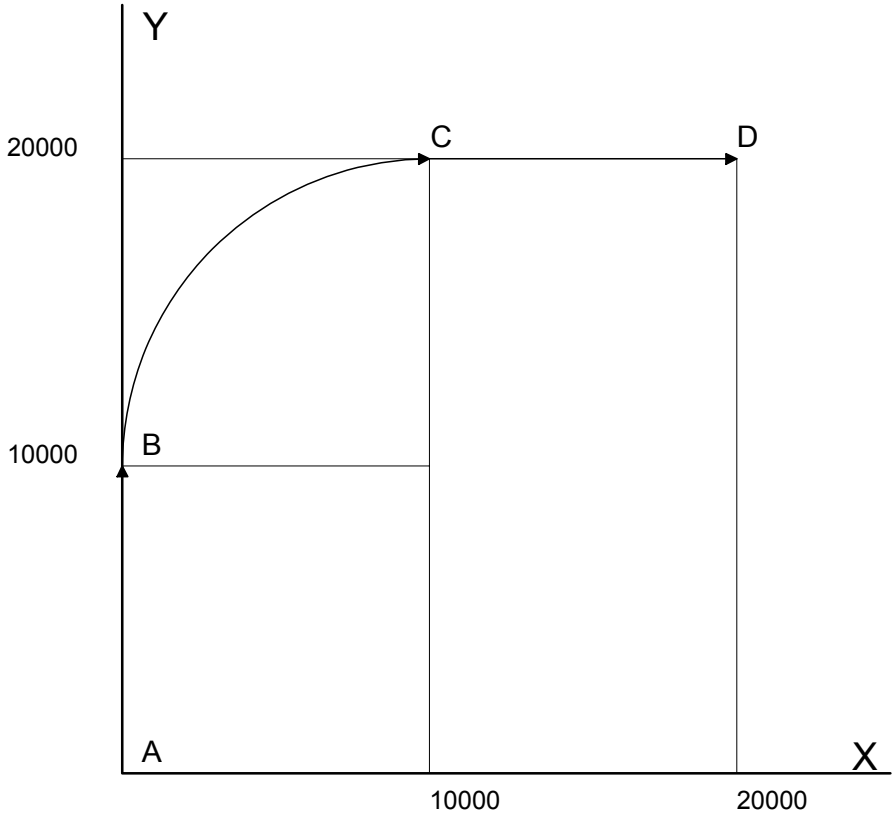


Figure.A.2 - X-Y Motion Path

The first line describes the straight line vector segment between points A and B. The next segment is a circular arc, which starts at an angle of 180° and traverses -90°. Finally, the third line describes the linear segment between points C and D. Note that the total length of the motion consists of the segments:

```
A-B     Linear          10000 units
```

B-C	Circular	$\frac{R\lvert\Delta\theta\rvert 2\pi}{360}$ = 15708
C-D	Linear	10000
	Total	35708 counts

In general, the length of each linear segment is

$$L_k = \sqrt{Xk^2 + Yk^2}$$

Where Xk and Yk are the changes in X and Y positions along the linear segment. The length of the circular arc is

$$L_k = R_k\lvert\Delta\Theta_k\rvert 2\pi/360$$

The total travel distance is given by

$$D = \sum_{k=1}^{n} L_k$$

The velocity profile may be specified independently in terms of the vector velocity and acceleration.

For example, the velocity profile corresponding to the path of Fig. A.2 may be specified in terms of the vector speed and acceleration.

VS	100000
VA	2000000

The resulting vector velocity is shown in Fig. A.3.

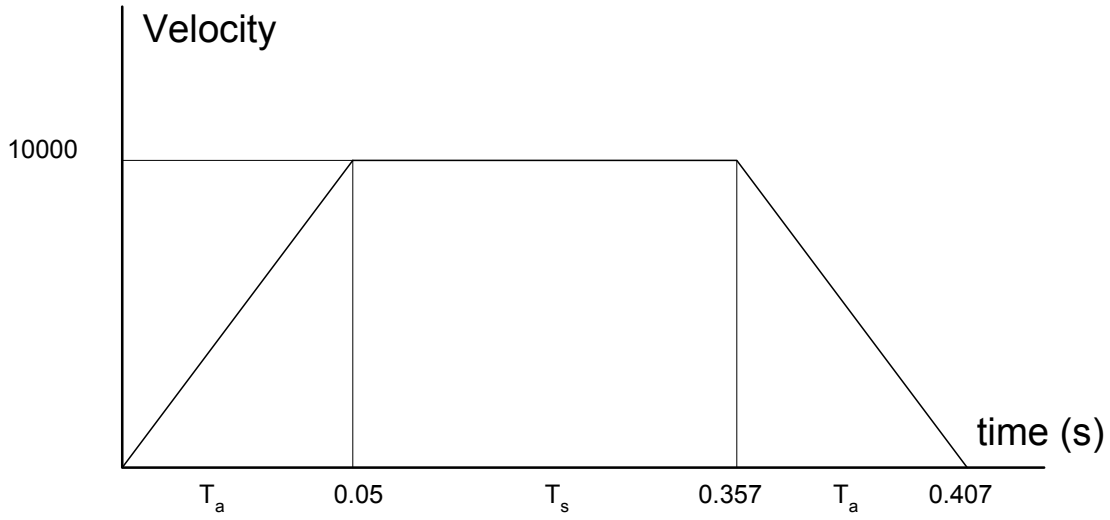


Figure A.3 - Vector Velocity Profile

The acceleration time, T_a, is given by

$$T_a = \frac{VS}{VA} = \frac{100000}{2000000} = 0.05s$$

The slew time, Ts, is given by

$$T_s = \frac{D}{VS} - T_a = \frac{35708}{100000} - 0.05 = 0.307s$$

The total motion time, Tt, is given by

$$T_t = \frac{D}{VS} + T_a = 0.407s$$

The velocities along the X and Y axes are such that the direction of motion follows the specified path, yet the vector velocity fits the vector speed and acceleration requirements.

For example, the velocities along the X and Y axes for the path shown in Fig. A.2 are given in Fig. A.4.

Fig. A.4a shows the vector velocity. It also indicates the position point along the path starting at A and ending at D. Between the points A and B, the motion is along the Y axis. Therefore,

Vy = Vs

and

Vx = 0

Between the points B and C, the velocities vary gradually and finally, between the points C and D, the motion is in the X direction.

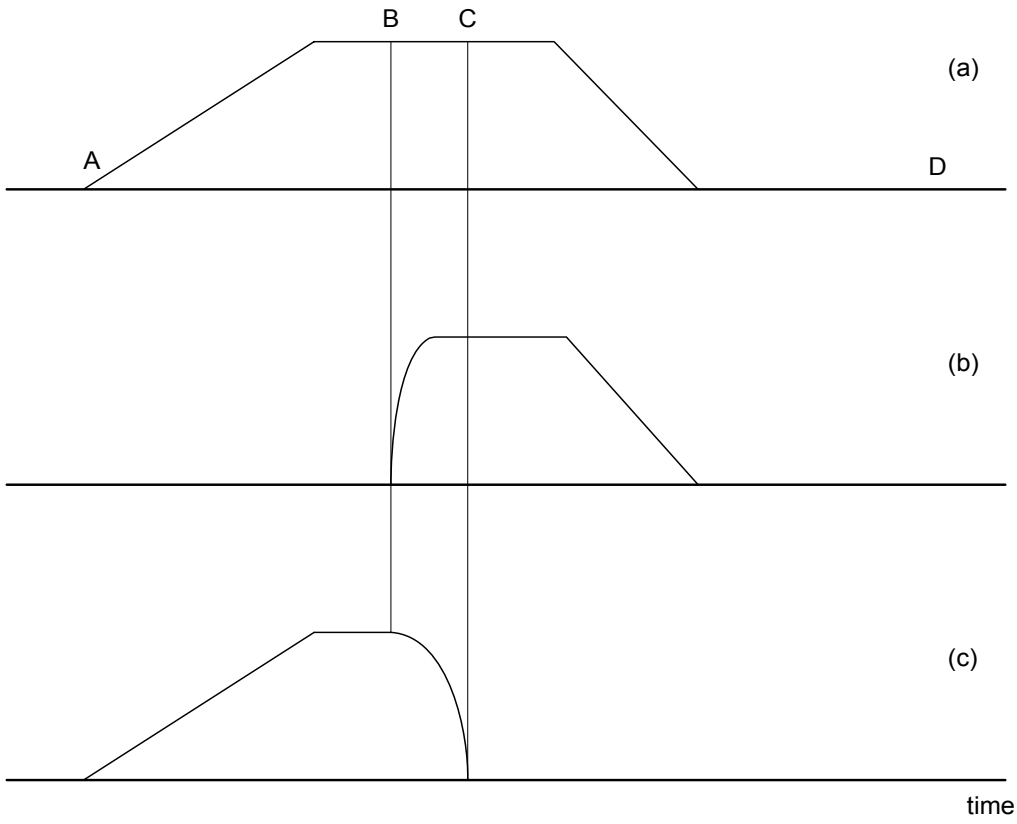


Figure A.4 - Vector and Axes Velocities

List of Other Publications

"Step by Step Design of Motion Control Systems"

by Dr. Jacob Tal

"Motion Control Applications"

by Dr. Jacob Tal

"Motion Control by Microprocessors"

by Dr. Jacob Tal

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Attendees must have a current application and recently purchased a Galil controller to attend this course.

TIME: Two days (8:30-4:30pm)

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FTP: www.galilmc.com/ftp

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